Space Flight Report

TO THE NATION

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Edited by

JERRY GREY and VIVIAN GREY

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For Jacquelyn Eve and Leslie Ann,
and all daughters and sons who may
someday find the answers to these questions posed by their parents.

VG and JG

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FOREWORD

WERNHER VON BRAUN

SPACE FLIGHT REPORT TO THE NATION recapitulates the American Rocket Society's massive effort to inform the American people of our rapidly accelerating space program. In this volume, our space vehicles are described by leading scientists and engineers in the field of vehicle engineering, and their scientific and exploratory missions are explained by equally well-qualified individuals. In addition to the scientific and engineering aspects of astronautics, the all-important global influences of astronautics are discussed in terms of their military, political, and economic effects. And since no report to the nation on space flight would be complete without some mention of the so-called space race between the United States and the Soviet Union, a panel discussion on this topic also is included.

In short, we have here a book which sums up the status of astronautics as it exists today.

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PREFACE

VIVIAN GREY and JERRY GREY

The achievement of space flight on October 4, 1957, marked a turning point in the history of this planet and of our civilization. On that date the Soviet Union launched the first artificial earth satellite.

Rarely had an engineering and scientific achievement aroused the interest and enthusiasm of so many. Yet the event had burst upon a world almost completely unprepared for space travel. Few persons were oriented to the new view of the universe that it implied, and even fewer had any real knowledge of the technical aspects of the achievement.

In the confusion following the Soviet announcement, the people of the United States turned to their country's rocket and space enthusiasts. They discovered that the nation had an organized and well-integrated core of men and women who were technically and scientifically competent in this field. They also found an established and functioning professional society, the American Rocket Society, whose purpose was to further the knowledge and skills necessary for space research.

Founded in 1930, the American Rocket Society had been ad-

vocating advancement in the field of astronautics for more than a generation. The announcement of SPUTNIK I was merely a confirmation of the society's basic thesis that space flight could be achieved. The members of this organization were prepared and qualified to accept the challenge of the space race.

Many of the people to whom the nation now turned to lead its rocket research program had often in earlier years been referred to as "unscientific" or "eccentric." The American Rocket Society had originally been organized by a group of these enthusiastic amateurs intent upon conducting experiments with rockets. Their "laboratories" were isolated buildings or deserted fields. They worked with materials and under conditions considered too hazardous for inhabited areas. Many financed their own research. The goal of this group was to develop rocket designs and propellants suitable for the achievement of space flight.

However, the pace and impetus of rocket research in recent years has placed the field far beyond the realm of the amateur experimenter. The role of the American Rocket Society has shifted, until today the Society functions as a communications center for the space industry. It services its members by establishing programs, publishing journals, encouraging student interest, and serving as spokesman for the scientists and engineers in the space field.

The American Rocket Society membership has also recognized that space flight has become a topic of general public interest. As part of its activities in providing public information on the subject, the Society conducted a conference called "Space Flight Report to the Nation" in the New York City Coliseum October 9 to 13, 1961. The purpose of the meeting was to present the field of space flight in its proper perspective to both the technical community and to the interested general public. Four of the panels conducted during that conference served as the basis for this book.

The panels were conceived and organized by Jerry Grey, Associate Professor of Aeronautical Engineering at Princeton University, and an Editor of this book. His philosophy in creating the panels was to synthesize and summarize the current state of space flight by focusing on four areas vital to astronautics: missions, vehicles, global effects, and a comparison of the United States and the Soviet Union with respect to the space race.

The views expressed in this book reflect the thinking of some of the most respected leaders of the space industry. Each con-

tributor is a leader in his field. This volume is the first authoritative review of space-oriented disciplines and influences. It was compiled so that this unique moment in history might be permanently recorded.

It is the Editors' belief that we should chronicle the problems, the plans, the humor, the dreams and, above all, the facts of our first steps into space. This book reflects the Editors' thesis that our civilization is poised at a pivotal point in our planet's history. We are well aware that we stand at the threshold of a new era in space. Yet we are also aware that, even though committed to the space race, we must acknowledge and attempt to resolve the still unsolved problems that plague the Earth.

The Editors wish to thank Miss Helen Doherty for her assistance in the preparation of the manuscript.

VIVIAN GREY and JERRY GREY
Princeton, New Jersey
July 15, 1962

I. The Missions

EDITORS' INTRODUCTION

"MISSIONS" is the popular term used to describe the various purposes of our space program. The successful completion of a mission is the objective and reason for space flight as it now exists. This section deals with the missions of the current United States space programs.

Dr. Kantrowitz keynotes this section by observing that scientists are not always able to predict the areas of future scientific investigation. His thesis is based on the research growth in the aerospace industry during this last critical decade.

Our first space pioneering task was the "mission" of learning as much as we could about space itself. The first exploratory equipment for space research was the high-altitude balloon. This was followed by "sounding rockets," simple vehicles fired almost vertically to explore the upper atmosphere and near-space regions above the earth. They carry instruments which "telemeter" their data back to ground stations. After their messages have been sent, the sounding rockets fall back to earth.

The first true space flight in 1957 marked the beginning of the use of earth satellites for the scientific exploration of near space. Dr. Friedman, one of the early pioneers of space science in the United States, describes the accomplishments and goals of these sounding rocket and satellite experiments. Their importance is illustrated by the fact that the greatest number of our satellites have been used for this mission: the exploration of near space.

Dr. Pickering extends our scientific exploration farther out into space. With the use of our "probes"—unmanned, instrumented space vehicles—we have already begun to explore the region out to the moon. Dr. Pickering summarizes these experiments and discusses what we have learned about "cislunar" and "interplanetary" space through the measurements collected and telemetered back to earth. He also describes the present program for unmanned lunar flight and comments on interplanetary flights. These are the missions planned for the next decade.

Although the exploration of space remains the dominant mission in our space program, two other earthbound projects are rapidly claiming a major share of our research attention. Space technology has given impetus to the fields of communications and meteorology, both areas providing us with not only new information and concepts, but also some immediate prospects for useful applications of the space program.

Satellites can send and receive signals between parts of the earth that cannot communicate through any other channel. They have proved to be an invaluable tool in this area, as well as a source for new types of communication systems. These new developments in the field of satellite communications are discussed by Dr. Pierce. He emphasizes the potential role of satellite research in providing improved television and telephone system communications to all areas of the world.

Weather forecasting and the analytical techniques of meteorology have been revolutionized as a result of advances in space technology. The use of satellite observations to assist in the analysis and prediction of weather is described by Dr. Reichelderfer, Chief of the United States Weather Bureau. He tells how cloud photographs made by the TIROS weather satellites, when used to supplement more conventional techniques of meteorological analysis, have provided us with one of the most useful technological accomplishments of our age. He observes that the influence of satellite ob-

servations of this type may yet fulfill one of man's oldest dreams—the control of weather.

The concluding mission is manned flight into space. Dr. Gilruth describes the mercurial growth of this program in the United States. He cites two programs as examples of our unbelievably rapid technological advancement: Project MERCURY, which culminated in the now well-known orbital flights, and Project APOLLO, which will implement President Kennedy's goal to "put an American on the moon by 1970."

PROLOGUE

ARTHUR R. KANTROWITZ, *Director,*
Avco-Everett Research Laboratories

THIS SECTION deals with "Missions In Space" which are already set up as programs. Not only should we examine these "current events" in the space field, but we should also assess as quickly as possible which of today's missions will be of importance tomorrow.

An interesting commentary on our judgments is that missions which may once have seemed trivial become clearly important in the light of history. The "trivial" missions need to be developed first. Once they become important, we will easily recognize them as such.

It is my view that our ability to invent new missions will pace the rate of our space progress. We must therefore bend every effort to make realistic assessments of what can be done in the future.

It is not our intention here to view the space program in terms of its history or to dwell on prophecy and speculation about the future. The missions selected for discussion are those in which we are now actively engaged. It will be noted that all of these missions are characterized by the fact that we gain a great deal from a very

small weight in space, and that their design is governed by the enormous cost of launching objects into space. The current cost is about $1,000 per pound in orbit. The cost has been dropping in the past few years, and although it is difficult to predict just how far and how fast it will come down, we can at least estimate how useful this reduction can be.

We have noticed that every time the cost of putting things in orbit is reduced by an order of magnitude, the number of projects that become profitable and desirable increases by an order of magnitude. We must therefore ask by how many orders of magnitude we could conceivably reduce the cost of launching objects into space without changing the laws of nature. The energy cost of putting things into space, if we buy it the way we usually buy energy, amounts to only a few cents per pound, as compared with the overall figure of $1,000 per pound that I have mentioned. This is one way to measure the great potentiality of these missions.

It is clear, therefore, that as we become able to decrease by orders of magnitude the cost of launching objects into space, we can expect order-of-magnitude increases in the number and complexity of the missions. Thus the missions discussed here, advanced as some of them may seem, represent only the bare beginnings of our venture into space.

1 SOUNDING ROCKETS AND SCIENTIFIC SATELLITES

HERBERT FRIEDMAN, *Superintendent of Astrophysics and Atmosphere Division, United States Naval Research Laboratory*

EVEN before the launching of the first Earth satellite, space science achieved a decade of remarkable advances with the aid of rocket probes capable of reaching heights of only 100 to 200 kilometers. The structure of the upper atmosphere was exposed to direct observations; ionospheric electron density profiles were measured up to the F-2 region; the solar spectrum was mapped through most of the range of ultraviolet and X-ray wave lengths; stellar ultraviolet astronomy had its beginnings in a mapping of spectra from early type stars; energetic particle fluxes were detected in the auroral zones; the phenomenon of radio whistlers, which indicated the extension of the ionosphere to heights as great as 10,000 kilometers, was observed; and the existence of an extended hydrogen geocorona, the cloud of hydrogen surrounding the Earth out to distances of the order of 10 radii, was inferred

from the scattering of the ultraviolet resonance Lyman-alpha line of hydrogen in the night sky.

But between the Earth and the sun, the interplanetary medium lay virtually unexplored and posed many puzzling questions. For instance, where do the solar atmosphere and the Earth's atmosphere end? Where is the boundary of the geomagnetic field? How is the galactic field modified in interplanetary space? Is there a static interplanetary gas, and if so, what is its composition? Is there a solar wind that blows strong and steady, or only a mild breeze of plasma sweeping past the orbits of the nearby planets?

To all of these questions, satellites and deep space probes have already given inital answers. I think we would all agree that the most important discovery of space exploration with rockets and satellites thus far was the discovery of the Van Allen belts, which are composed of electrons and protons trapped within the geomagnetic field that extends out to about 15 Earth radii. Where the magnetic field is strong, close to the Earth, there exists a relatively stable inner zone in which electrons and protons may be trapped for an average life of about ten years. At greater distances in the outer zone, the fluctuations are of the order of factors of 1,000, which are directly related to the arrival of bursts of solar plasma. The visible auroral zone apparently defines the base of the turbulent magnetic shell that marks the interface between the atmospheric neighborhood of the Earth and the interplanetary medium.

Perhaps the outstanding puzzle of the Van Allen belts is the mechanism that converts low-energy solar-plasma particles to the high-energy particle flux observed in the belts' outer zone—of the order of 10^7 electrons per square centimeter per second, with energies exceeding 200 kilovolts. A great deal of study is also needed to reveal the full spectrum of very-low-energy electrons and protons that must be responsible for the major geophysical effects: *e.g.*, atmospheric heating, magnetic storms, the aurora and airglow.

For 50 years cosmic rays have been measured from sea level to mountain tops, from aircraft and balloons, and, more recently, from rockets and satellites. Some come directly to us from the sun, but the highest-energy particles come from the remote regions of space. Over a solar cycle, the cosmic-ray flux at the Earth varies from maximum to minimum in opposite phase to the changes in sunspot numbers. PIONEER V settled the basic question of whether the cosmic rays were modulated by the geomagnetic field or by

an interplanetary field pervading the entire solar system: data transmitted over the course of ten million miles proved that cosmic-ray changes observed near the Earth appeared simultaneously throughout the solar system, at least out to these great distances. The modulations are produced by magnetic fields, trapped in solar plasma clouds that drift through the interplanetary medium.

More recently space vehicles carrying plasma probes have begun to define the characteristics of the magnetized plasma clouds in interplanetary space. Under quiet conditions the gas density may not exceed one particle per cubic centimeter. This is in great contrast to our ideas of a few years ago, when we considered concentrations of the order of 600 to 1,000 per cubic centimeter. There are transient clouds which appear to carry ten to 100 ions per cc. with speeds of the order of a few hundred kilometers per second.

I believe that astonomy, more than any other field of science, may be revolutionized by the establishment of observatories above the atmosphere. An impressive list of accomplishments can already be cited in the fields of ultraviolet and x-ray spectroscopy and photography, which extend the astronomers' spectrum far beyond the classical optical window and the more recently-explored radio window. Equally exciting prospects await the establishment of large telescopes in space. A mirror of sufficiently large size operating in the ultraviolet can far exceed the resolving power of any ground-based telescope. For example, a one-meter telescope has a theoretical resolution of a tenth of a second of arc. A ten-meter telescope, which, of course, is a very large instrument, would have a resolution of 0.01 second of arc. Because of flexure in a gravitational field, such a large telescope really would have to orbit in space to maintain this figure. Its high resolution could probably not be maintained if it were placed on the Moon.

Many things can be done with these large telescopes. Astronomers believe that much of the material in the galaxy is in the form of stars too faint to detect with present instruments. If we could detect these faint stars, we would obtain a much more accurate inventory of the total mass of stars in the galaxy.

What we see with present equipment may represent only one-half to one-tenth of the material that is actually there. There may be some stars, so-called "black dwarfs," which are in the final stages of extinction and do not radiate enough energy to be visible. There may also be a lot of gas in the form of molecular hydrogen.

Radio astronomers have found a very potent tool in the 21-centimeter wavelength to study the distribution of atomic hydrogen, but we have no means in the visible spectrum of finding molecular hydrogen. Yet in the ultraviolet there are good possibilities of detecting molecular hydrogen. There is strong reason to believe that atomic hydrogen, catalyzed by dust particles in space, would recombine to form molecular hydrogen as a major constituent, and this would be of fundamental importance to determine.

I could go on and indicate many other applications, but when I speak of a telescope of the order of ten meters in size, many will immediately say, "This is science fiction!" At the moment I would be inclined to agree, although today nobody dares to sound a thoroughly discouraging note about any projects to be conducted in the future. If we talk about men servicing vehicles in space, there is no reason why we should not talk about a telescope in space.

But let us come back to things closer to present-day programs. Even if we cannot produce telescopes of such quality, we can make high-flying telescopes for ultraviolet light, which is almost completely absorbed by our atmosphere. For the theories of stellar evolution and the structure of stellar atmospheres, we need to know the absolute fluxes of radiation from stars in the ultraviolet. The most interesting stars—those that have been recently born and radiate practically all of their energy in the ultraviolet—can today be gauged only by looking at a relatively weak tail of emission which stretches into the visible spectrum. Experiments already conducted, even with simple rocket techniques, have shown that there are wide discrepancies between the fluxes measured in the far ultraviolet and what present-day theory predicts. We are certainly going to have to modify these theories in rather radical ways.

Now let me come back to "Earthy" reality, and quote from my own experiences in conducting rocket astronomy with present-day techniques.

Figure 1 is a photographic spectrum obtained at the beginning of our rocket research program, showing the first extension of the solar spectrum into the ultraviolet. The figure shows a series of spectra obtained as the rocket ascended. A few spectral absorption lines extend down to about 2,200 Angstroms.

Figure 2 shows the result of an experiment done in August 1961 with an Aerobee rocket, using a rather remarkable instrument which folds the spectrum on itself so that it can all be recorded on

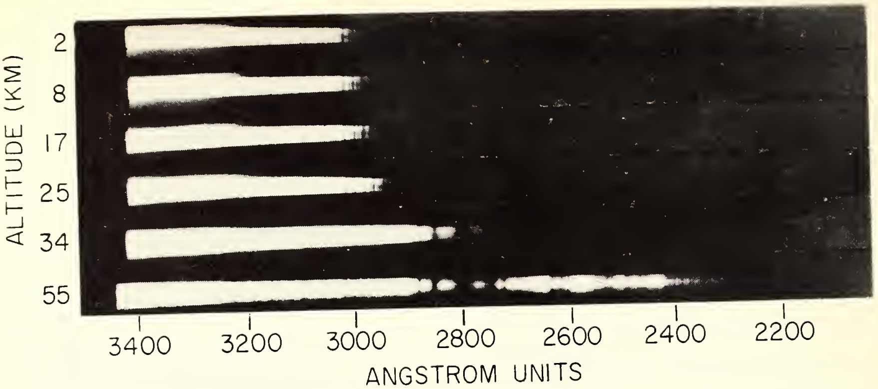


FIGURE 1. The first ultraviolet spectra of the sun recorded from above the Earth's ozone layer. The photographs were made by the United States Naval Research Laboratory with a V-2 rocket on October 10, 1946.

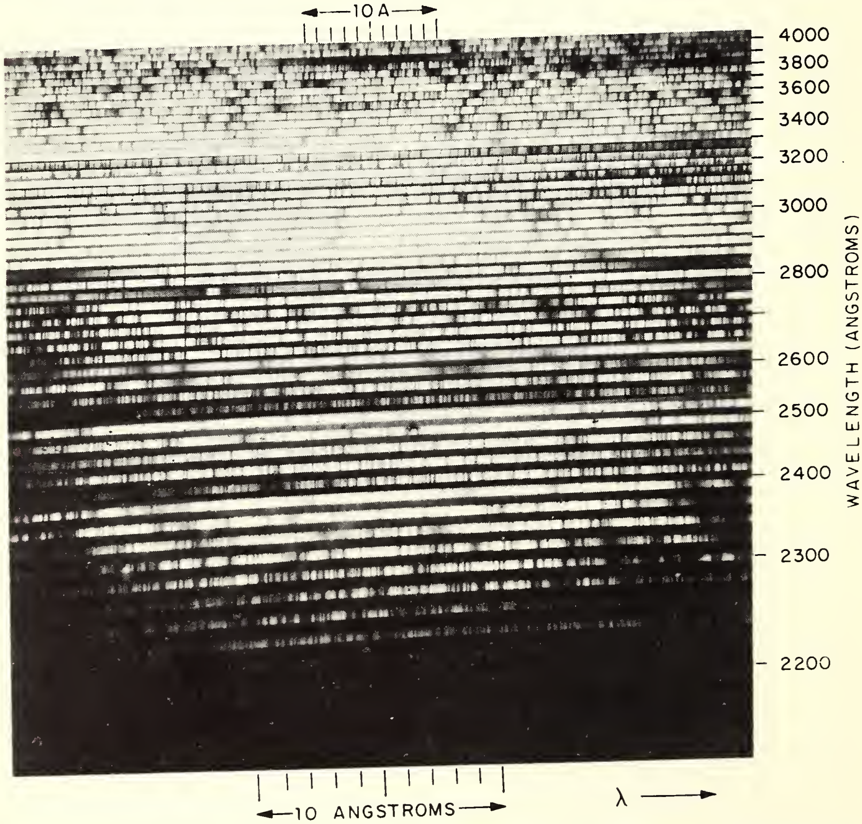


FIGURE 2. The ultraviolet spectrum of the sun, photographed from an Aerobee-Hi rocket August 29, 1961, by the Naval Research Laboratory.

a one-inch-square piece of 35-millimeter film. We see here the same region of the spectrum shown in Figure 1. Instead of being able to measure only a few dozen lines, we are now able to observe about 5,000 lines in the same range. This is highly satisfactory progress for ten years of work, and it is a great credit to Dr. Tousey and his associates at the Naval Research Laboratory, who have carried on this program step by step over the past ten years.

This is the kind of sophisticated result which, as Professor Donald Menzel of Harvard remarked upon seeing the photograph, could keep a staff of astrophysicists busy for the next five years eking out all of the theoretical information to be derived.

I recommend strongly that those who plan to work in this area of astrophysical research provide themselves with the "insurance" offered by small-rocket soundings. We want to keep our eyes on the large goals of the future, from which we may certainly expect the most exciting results, but it is also essential to continue with small rocket experiments which can provide a large harvest of scientific data in the immediate future.

2 SOLAR SYSTEM EXPLORATION

WILLIAM H. PICKERING, *Director, Jet Propulsion Laboratory*

I WOULD like to focus on the objectives of the unmanned lunar and planetary exploration programs. This view of our research will include some general discussions on our studies of the physics of the moon and the planets, solar and interplanetary physics, biosciences, extraterrestrial life, and astrophysics.

So far eleven mission launchings with lunar or planetary objectives have been attempted by the United States. These include five PIONEER missions, three ATLAS-ABLE missions, and RANGERS I, II, and III. PIONEERS IV and V can be considered essentially successful, and PIONEERS I and III, partly successful. PIONEERS I and III each reached near-escape velocity, which carried them to altitudes of about 70,000 miles, PIONEER IV passed the Moon at a distance of about some 30,000 or 40,000 miles and is now in a solar orbit, and PIONEER V also went into a heliocentric orbit which carried it into approximately the orbit of Venus.

These flights have provided considerable scientific informa-

tion. PIONEER I made the first radial traverse of the Van Allen radiation belt and the first measurements of the interplanetary magnetic field; PIONEER III discovered the second radiation belt and defined its limits; PIONEER IV carried out further measurements of the radiation belts. In PIONEER V, radio communication was obtained out to a distance of about 22 million miles, and this included measurements of interplanetary radiation far beyond the Van Allen belts. PIONEER V was also used as a means of calculating the so-called "astronomical unit."

Just for reference, I think we might note that the U.S.S.R. has successfully launched three lunar experiments and one planetary probe. The lunar experiments conducted measurements of the radiation and magnetic fields in cislunar space, in addition to the well-publicized photographing of the back of the Moon and the impact on the Moon. The planetary probe obtained some measurements out in interplanetary space, but its radio failed only a few days after launching.

The programs currently active in the United States include RANGER and SURVEYOR, which are the present unmanned lunar programs. Several RANGERS have already been launched. RANGER's principal purpose is to photograph the moon and to undergo rough lunar impacts.

The first kinds of experiments to be conducted by RANGER are the interplanetary measurements necessary to complete a trip to the Moon and return to Earth. These will include measurements of radiation, magnetic fields, micrometeorite density, etc. The radiation measurements will probably be more complete than those obtained by other probes, in that they will completely cover the range of energies from the very-low-energy solar-plasma particles up to the high-energy cosmic-ray particles. Shortly before the impact, the vehicle is to look at the Moon with both a TV camera and a gamma-ray spectrometer. In addition, a radar set will signal the approach of the Moon, and some measurements of radar reflectivity of portions of the Moon surface can thus be obtained. The impact vehicles will also carry an experiment which is primarily a seismometer and will operate after the vehicle has landed on the Moon.

The next class of experiment will be the SURVEYOR, which is designed as a soft-landing device; that is, it will land on the Moon with a speed of only a few feet per second. This slow speed will

protect the complex array of instruments the SURVEYOR is to carry. In a general way the SURVEYOR may be considered a scientific station on the Moon. It will provide experiments on the chemical and physical properties of the lunar surface. It will also measure fields and radiation.

Moving farther out into space, we come to the first planetary program, called the MARINER. Mars and Venus are the nearest neighbors to the Earth, and it is therefore to be expected that the first measurements will be conducted by probes to those planets. The early probes will be fly-by experiments which will go fairly close to the planets and make observations enroute and in passing. These will be followed by orbiting and landing experiments. In this stage, perhaps a part of the vehicle will land on either Mars or Venus and transmit signals to its parent vehicle, which will have remained in the vicinity of the planet. This parent vehicle will relay the signals back to Earth.

When we consider the problem of exploration of the planets, we open up an entirely new area of science. We really know very little about the planets, since our knowledge is based only on astronomical observations taken from the surface of the Earth. The MARINER program should make it possible to move one step beyond observations taken from the top of the atmosphere by balloons, sounding rockets, and earth satellites. This new knowledge can only be acquired by having a vehicle in the immediate vicinity of the planet. All of us can enjoy speculating on what results the instruments in the MARINER will find; we do know they will open up a tremendous field of new research. Finally, we look forward to the prospect of landing on the planets and answering in detail the fascinating question: Is there life on the other worlds of our solar system? If so, what is the form of that life?

Figure 3 indicates some of the problems we know we will have to face in planetary exploration. Each expedition must be limited to reaching a planet within a reasonable communication distance, and to launching a vehicle of reasonable size. The launching times will be determined by the astronomical facts of the orbits of the various planets. Venus, for example, will come close enough to the Earth to give us an opportunity about once every 19 months. If we are not ready to launch with complete reliability and reasonable assurance of success when the favorable planetary dates arrive, we shall simply miss the chance. Either we launch on schedule or

wait several years. This is rather different from the normal guided-missile exercise.

Both the planetary and the lunar programs involve the problem of communication over great distances. In anticipation of these communication needs, the United States has already established a facility for tracking and receiving signals from the planets. This facility, shown in Figure 4, consists of three stations located in California, South Africa, and Australia. The three stations are roughly 120 degrees apart around the Earth, so that vehicles

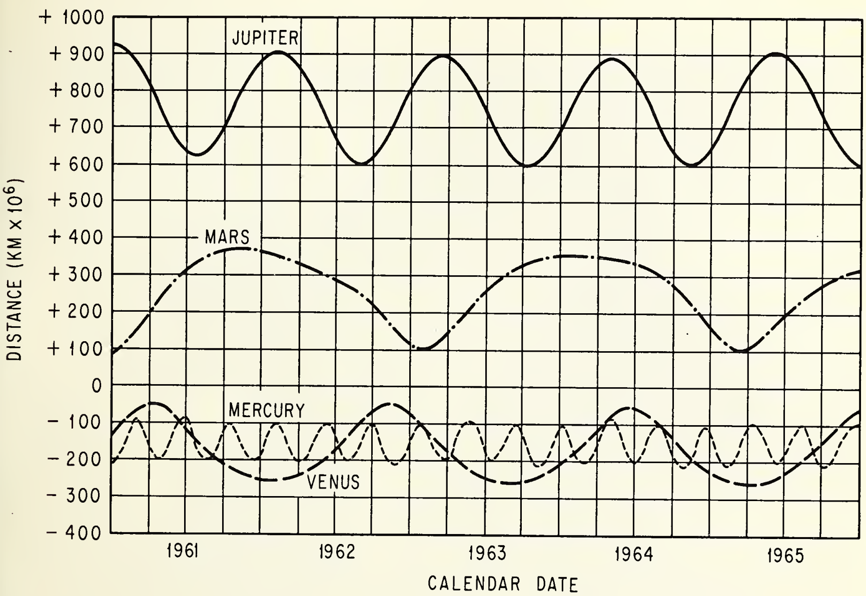


FIGURE 3. The schedule of approaches of the planets to the Earth (represented by 0).

launched on lunar and planetary missions can be observed at all times by at least one of them. The curves in the chart indicate the coverage from the various stations of vehicles at various altitudes.

The demands of lunar and planetary missions require that we select launching vehicles which have the ability to give the payloads large amounts of energy. The achievement of escape velocity requires about twice the energy needed for the current satellites. This means that the payloads to be carried to the Moon and the planets will have to be correspondingly reduced from those that

can be put into satellite orbits. The missions that can be conducted will be sharply circumscribed by the launching vehicles available.

The present United States program envisages using first the ATLAS AGENA, then the ATLAS CENTAUR, and eventually the SATURN. TITAN II also is being considered for certain missions. The SATURN-launched planetary program will be known as the VOYAGER. The title of this last program appears especially appropriate. Though we are preparing for the journey to the planets to the best of our abilities, we still do not know what the traveler will find at his destination.

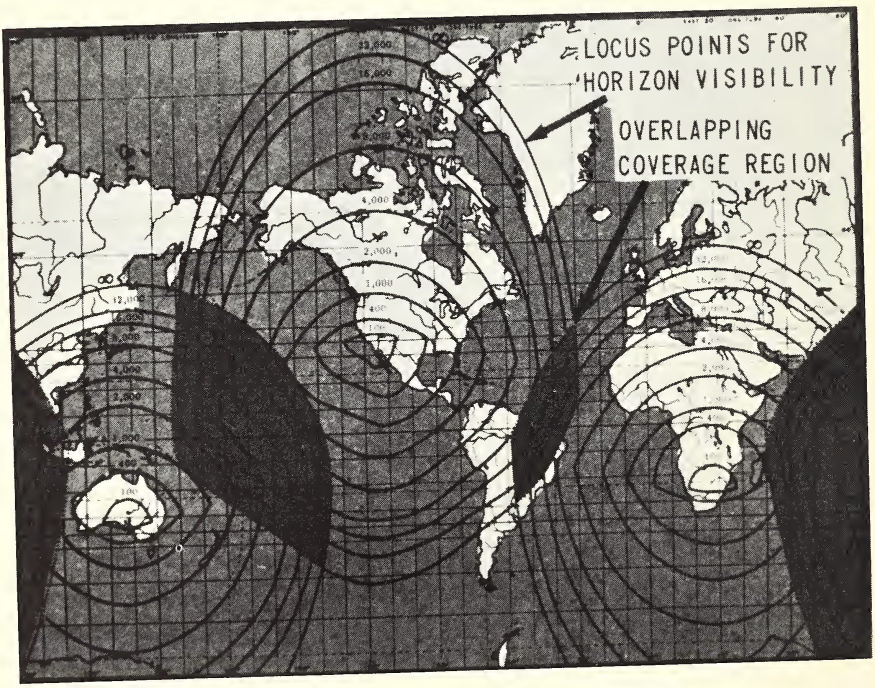


FIGURE 4. Coverage of space vehicles by radio from three stations on the Earth.

3 METEOROLOGICAL APPLICATIONS

FRANCIS W. REICHELDERFER, *Chief, U.S. Weather Bureau*

METEOROLOGY should be one of the most sophisticated sciences, but up to the present time it has not had enough data, not enough measurements of atmospheric conditions. Meteorology has not been able to, as Lord Kelvin said, express our knowledge in numbers on a large scale. We have had thermometers, barometers, and other instruments, but they have given inadequate samples. We have been forced into practical services of meteorology because of the great human need for forecasts and warnings of storms. After British meteorologists first started their daily weather service in the late nineteenth century, they realized that they lacked enough data to make accurate predictions and stopped their forecasting services. But before long they were forced by popular demand to resume the service.

We are now at the beginning of a new era in which meteorology will become more and more a quantitative science. Not the least of the contributors to this new era are the rockets, satellites, and other devices for "sounding" the air envelope surrounding our

earth. Many questions can be answered by these devices to complete the meteorological picture. We need to know how much influence is exerted on the lower atmosphere by conditions in the higher atmosphere, and how the daily variations in weather take place all over the globe, so that we may try to settle the question as to whether or not the radiation and other variations in the high atmosphere really affect the weather to any great extent.

Normally we oversimplify the weather. We look out the window and we say it is clear or foul. Clear weather may make us want to get out for golf. Bad weather may delay an airplane flight or change plans for a picnic. It seems very simple. Actually the atmospheric sciences run a very wide range of human interests, from fallout to food supply. It was Ellsworth Huntington, I believe, who said that climates may be in part responsible for wars, so perhaps eventually we will be able to pin everything on the weather and climate!

Atmospheric phenomena are far more detailed and complex than we normally think, and the space age is now bringing us the numbers and the data to make this field a truly quantitative science. We have made real progress in recent years: *e.g.*, exploration and forecasting of events in the atmosphere with the use of computers, which was pioneered by John Von Neumann, Carl Rossby, and others. Each day now we have two maps computed entirely without subjective or personal influence. The computer is also being used for a project under Dr. Smagerinsky, among others, to determine what happens when the basic factors in the atmospheric circulation are varied. Its purpose is to explain the longer-term trends, for it is obvious that if we are to consider engaging in large-scale weather control or modification, we must know more about how to predict the variations that will occur. Think of the uncertainty we would cause if we added artificial unknowns to the already vast mixture of natural unknowns in the atmosphere. We have seen in the field of rain-making what a "can of worms" this can make!

The influence of space flight on the science of meteorology is best illustrated by photographs from the TIROS meteorological satellites. Composites, or mosaics, of these photographs show cloud patterns over large areas of the Earth—nature's own weather map—and locate storm centers. When a TIROS photograph is superimposed on the isobars of a conventional weather map, we see more than man has ever seen of the weather. It gives information about the

jet stream, cloud arrays in the theoretically clear space, and so on. These data give promise of some basis for prediction, because they are systematic. The composite provides far more information than we could ever obtain from earthbound station and ship reports alone. It gives details of the formation of vortices which we normally could never obtain from surface observations at sea.

Figure 5 is a simplified view of the Northern Hemisphere,

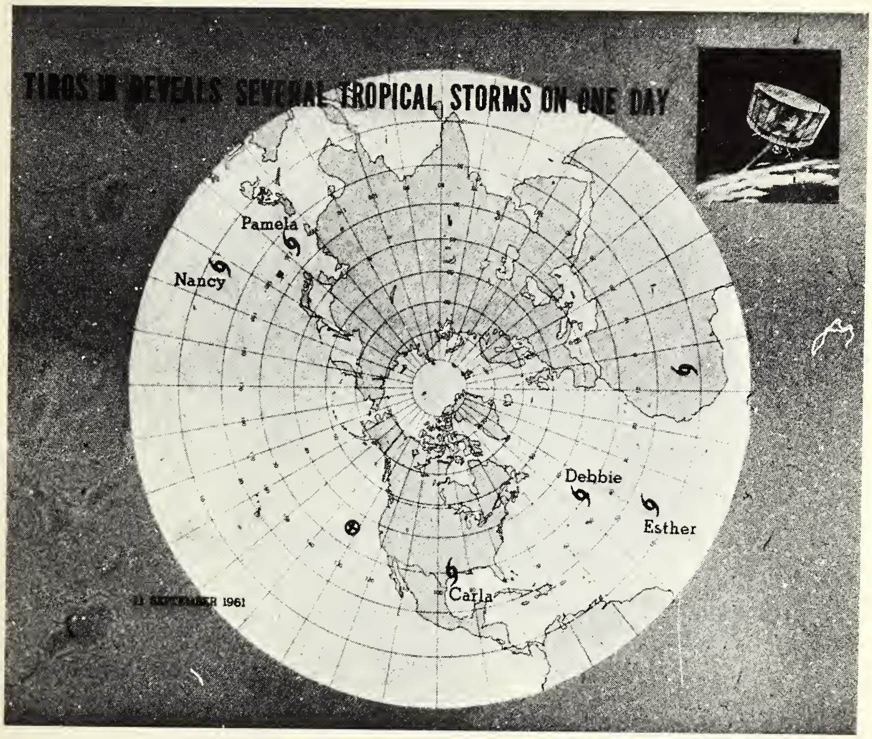


FIGURE 5. Cyclone centers detected by Tiros III in its orbits around the Earth.

showing the North Pole, North America, Europe, and Asia. This map might be called the "Hurricane Sextet." It is based on photos made on September 11, 1961 by TIROS III. It locates, first, the beginnings of a vortex (little more than a wave formation) over Western Africa. This did not develop into a tropical cyclone, although it showed some signs at that time. There is a storm center labeled Esther, which later came up the Atlantic Coast of the

United States. Hurricane Debbie had come along this course and then recurred a few days after this photograph was taken, causing severe gales and loss of life in the British Isles. The map also shows Carla just crossing the Gulf coast near Galveston, as well as two other hurricanes, one of which, Nancy, caused considerable loss of life in Japan. A small cyclone, not yet worthy of being called a hurricane, also appears in the Pacific just west of California.

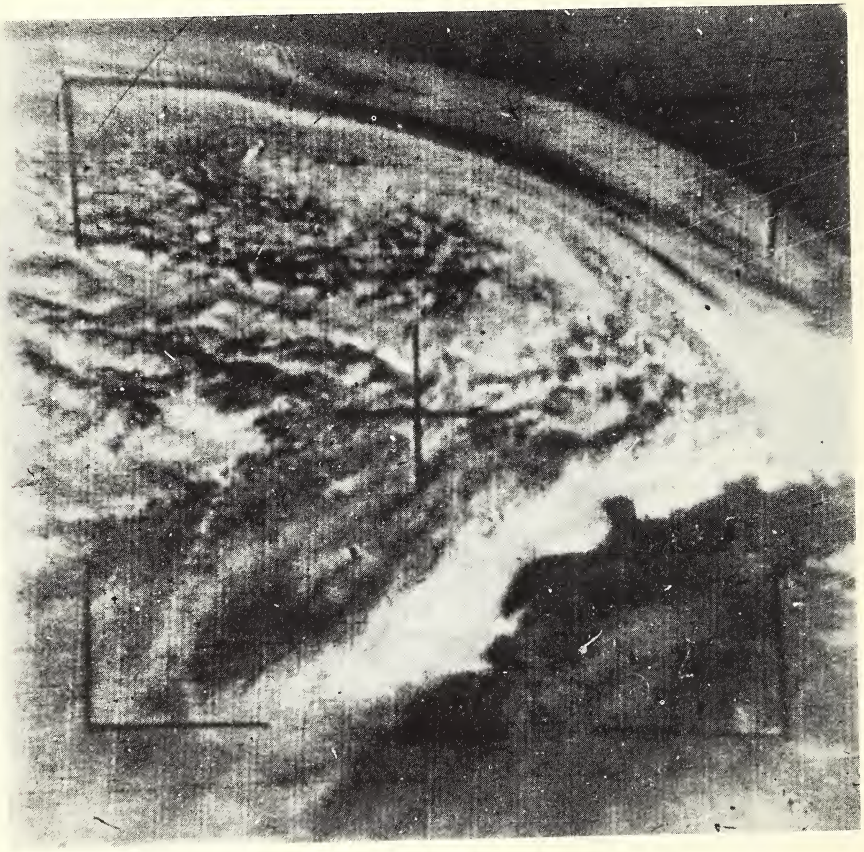


FIGURE 6. A Tiros photograph of clouds over the Pacific.

The significance is that with a few scenes photographed by a satellite we can see more about the clouds than we could ever hope to see with thousands of ships. This is one of the first evidences of the new era in meteorology.

Figure 6, showing an area of the Pacific west of Mexico, reveals the details of clouds, the spiral structures, a wealth of information

that could not possibly be obtained by surface observations, by radiosondes, or by anything except a bird's-eye view. The upper part of the photo shows a series of storms. Here, then, is one of the practical applications Dr. Kantrowitz mentioned—an immediate practical application, in which we transmit information within four or five hours from the time a photograph is taken by TIROS to stations all over the world, so that they can select the services or the information they need.

I have often heard the statement that satellites have only a large-scale application in meteorology. Figure 7, which is now

FIGURE 7. A Tiros photo of a Midwestern area and a ground plot of cloud conditions over the same area.

somewhat of a classic, demonstrates the potentialities of satellite observations for local weather forecasting. The square patch at the lower left in this photograph was sufficiently interesting to deserve special study. It was found that this cloud formation preceded the development of tornadoes over Oklahoma. We know that not all tornadoes are preceded by this type of cloud. Conversely, we do not know whether this sort of development is followed by tornadoes in every case, but the cloud "signature" may be recognized as a definite tornado indicator in some cases.

Figure 8 gives an overall view of various kinds of information that can be given by satellites. Some of these possibilities have al-

ready been realized; some are on the drawing board; and some of them have not yet been worked out.

Other things we can learn from satellite observations include, for example, the atmospheric heat budget and the effect of fluctuations in solar radiation and differences in insulation on the heat-absorbing atmospheric layers. Further, it should not be difficult to get a complete census of thunderstorms, which would have applications in communications, precipitation estimation, etc.

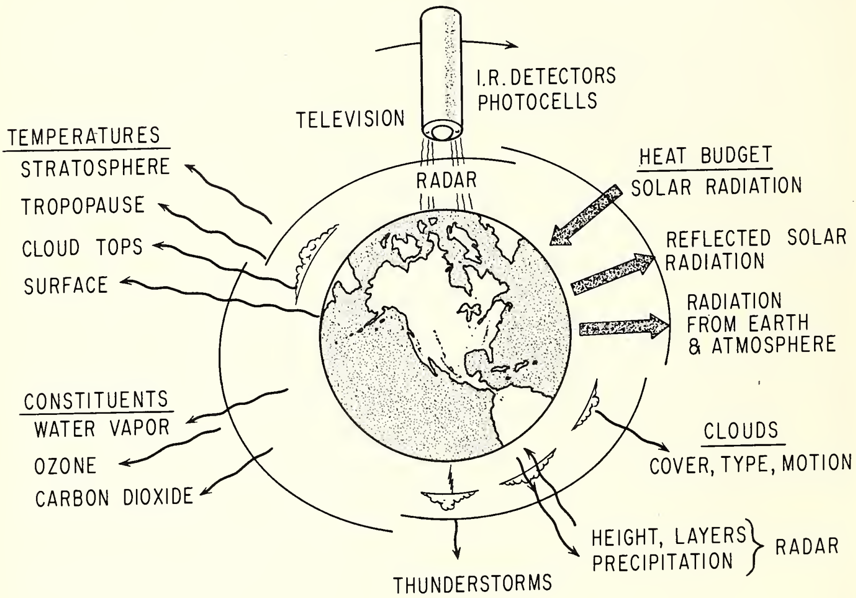


FIGURE 8. Information to be sought with satellites.

We use infrared measurements made by TIROS III to determine the heights of cloud tops over the ocean. Observations of snow fields are of great value to hydrologists in estimating the water that is available for storage, water supply, and irrigation, and for predicting floods. They show important things about breaks in the ice fields in the polar regions.

One of the most controversial and explosive subjects in meteorology today is the two-sided question of weather control. For example, while artificial melting of the North Polar ice cap would open up new lands to agriculture, etc., it would also put many

lands under 20 or 30 feet of water, including most of the ports of the world. Nevertheless, meteorologists are looking at the problems of weather control with much anticipation. One of the things we would like to do is to test theories of what would happen if the heat inflow over a large area of the globe were changed. This could have major effects on phenomena such as hurricanes, rainy seasons, etc.

I want to express our thanks to those to whom we are so indebted in our current meteorological program: NASA, the military services, and all the sister services that work so closely with the Weather Bureau.

4 COMMUNICATIONS APPLICATIONS

JOHN R. PIERCE, *Director of Research, Bell Telephone Laboratories*

IT HAS been said that our investments in space science will pay off through practical applications. I would like to point out that a great deal of the knowledge being used in space technology comes from more general fields of science. In particular, the electronic technology (transistors, solar cells, etc.) that goes into guidance systems was provided by branches of science and technology *not* directly inspired by space. In these so-called "practical applications," therefore, it is our investments in science and technology which are paying off, and not our investments in space alone.

New developments in technology at first seem rather isolated. Once airplanes were just for sportsmen, the telephone was a toy, and automobiles were amusement devices for the rich. Eventually, however, these things were incorporated in the general technology of the age. When airplanes became part of the transportation system, they began to involve communications, ground facilities, guidance

facilities, and navigation facilities drawn in from the rest of the current technology. Similarly, a great step is now being taken in bringing space into conjunction with an already thriving part of technology: the field of communications.

There is a tremendous communication technology in the world already. There are 80,000,000 telephones in this country, and about 60,000,000 in other parts of the world. You can pick up your telephone now and call any place in the United States, and also about 160 other political areas. Still, although we get very good service within the United States and to Europe and Hawaii by submarine cable, the service to some of the other lands is not too satisfactory, because it is by shortwave radio, which is limited in quantity and often also in quality. Similarly, microwave radio and cable systems, with repeaters every few miles, provide communication for television as well as for telephone within the continental limits, but the cables that now exist for overseas traffic are barely adequate, though more are being installed. There are now two cables to Europe, a cable to Hawaii, and other cables are being planned to Great Britain and Japan. The British Empire is planning a commonwealth communication system. Yet this growth rate is barely keeping up with the overseas telephone traffic, which is growing much faster than domestic traffic.

Satellites would provide a way of carrying ~~this~~ the increased communications burden by putting microwave repeaters in the sky. There are several different methods of doing this. The two principal proposals are: (1) a low-altitude system (about 6,000 miles high) of many satellites, or (2) following Arthur Clarke's original suggestion, a series of so-called "synchronous satellites," each of which is 22,300 miles up and remains fixed over a single spot on earth. However, if either of these systems is to become a reality, and not something that Arthur Clarke described in 1945 or that I described in 1955, tremendous improvements must be made in reliability, long life, and performance of the equipment in the space environment. We can achieve significant scientific results from an experimental satellite even if it does not function perfectly or functions for only a limited time, but communication relay satellites will be useful only if they keep going for years.

This is a difficult problem. Looking at the experimental evidence, we might believe it to be impossible. Project SCORE, launched on December 18, 1959, lasted only 33 days. COURIER, launched on

October 4, 1960, lasted 17 days. That is not very encouraging. The ECHO satellite is a passive satellite and is still going, but it is not the most suitable device for commercial communications.

Making calculations on expected reliability, we find that rather small, simple satellites with about 1,000 components might indeed last for several years, provided that the very best available components were used—components that have been tested over a period of years. Even then it is not easy. For example, there is a question of reliability during launch. Although the TITAN guidance system has been launched more than 40 times without failure, leading us to believe that electronic components can survive the rigors of launching, we cannot be quite sure that we will obtain sufficiently long life in space until a communication device has actually been launched.

Another problem is reliability of attitude control; *i.e.*, keeping the satellite always pointed in one direction relative to the earth's surface. This is desirable for both of the proposed kinds of communications satellite, in order to minimize the power necessary for signal transmission. For satellites only one or two thousand miles high, it may be practical to use the Earth's gravitational gradient for attitude control. A gravity device could line up a long, slender satellite so that its long axis pointed toward the earth. Unfortunately, this has not been, and possibly cannot be, accomplished at the higher altitudes. The forces involved are rather small, damping is inadequate, and getting the device initially launched is difficult. Alternative methods of attitude control utilize the gyroscopic effects of rotating wheels. Still others, which have been used in satellites but have not been expected to last for very long periods, use small gas jets similar to those on the manned MERCURY capsules.

Will all of these things really last in space for years? Everyone hopes that they will, but there are two points of view in this regard. Some say: "Well, it hasn't been *proved* yet that there is going to be any difficulty!" On the other hand, as an engineer I rather prefer to see a device actually give the described performance before I believe that it is really practical and satisfactory.

Coming now to the question of which satellite system will eventually be used, I do not believe that the present state of knowledge permits us to make this decision yet. It would, of course, be desirable to try several systems, but that does not seem to be in the cards. Although I feel sure that one day there will be a

24-hour satellite system, it is likely that the low-altitude satellites may become operational at a slightly earlier date.

The program that began in 1960 with the ECHO launching will continue with the launching of a second, 135-foot satellite in an 800 mile orbit. This will be followed by three more, to be launched simultaneously in a 1,700-mile orbit, as part of a communications project called REBOUND. The Army satellite system ADVENT is scheduled for launching at a somewhat lower altitude than the 24-hour satellite. This is a very complicated satellite, both electronically and with regard to its attitude control and station-keeping, and it is most interesting as a forerunner of true communications satellites. NASA's Project RELAY satellite, to be launched by a THOR-DELTA rocket booster, is intended to follow an elliptical orbit varying in altitude from about 600 to about 2,500 miles. There are two reasons for the elliptical orbit: first, it will be useful to explore the effects of the Van Allen radiation on communications satellites, and second, the available THOR-DELTA booster is not capable of putting it into a circular orbit high enough to be of any use. A similar satellite, TELSTAR, built by the Bell System at its own expense, has already been launched by NASA with spectacular success. Finally, NASA plans to launch a Hughes "SYN-COM" or 24-hour satellite. This is a simple little satellite, with a much more limited communication capacity than the lower-altitude devices, but it will be interesting to see how well it can be kept in a 24-hour orbit.

Most of these satellites will be capable of voice tests across the ocean, in cooperation with the post-office departments (which run the telephone systems) in England, France, Germany, and perhaps other countries as well. Italy and Japan, for example, are very interested.

These experiments are expected to provide much information about reliability. Ground stations will be put into service both in this country and abroad, and people will gain experience in tracking and using satellites. The SYN-COM satellite will provide data on attitude control of the simple gyroscopic or spin type, as well as the previously mentioned station-keeping capability. ADVENT will be an experiment in attitude control of a more elaborate kind. Other experiments have to follow these first satellites. It would be unwise for us to freeze our thoughts on the class of satellite communication system to be used before digesting the information we receive from these early experiments.

I predict a brilliant future for satellite communications as the first point of union between space technology and the other fields of technology and science. Space technology has not yet made a close and practical alliance with the technology that built today's world. Perhaps the communications field can bridge this gap.

5 MANNED SPACE FLIGHT

ROBERT R. GILRUTH, *Director, NASA Manned Spacecraft Center*

WITHIN the framework of our broad national space-research program, manned flight is just coming of age. The participation of human pilots in the space-flight program was recognized from the outset and was provided for by the organization of the Space Task Group concurrently with the establishment of the civilian National Aeronautics and Space Administration.

Project MERCURY was our initial undertaking. Although modest in comparison with future programs now being planned, MERCURY has been a difficult but inspiring task. In the few short years since its official inception, it has passed through the stages of research, development, engineering, design, and manufacture. We are now deep in the flight-test phase. I think perhaps the most direct description of the status of Project MERCURY today is that we have reached the *end of the beginning.*

As we approach the completion of the initially specified mission in this project, I think we can reflect with pride on a solid record

of achievement. The challenge presented to us at the outset was to conduct a research program with two objectives:

First, to investigate man's capabilities in the space environment. I might add that the pilots in our program and many of our other people now prefer to say "confirm" man's capabilities in the space environment, because our successful manned flights make that a more appropriate term.

Second, and concurrent with the first, to develop manned-space-flight technology as a basis for the conduct of much more ambitious undertakings, including manned exploration of space and the planets.

Let me review very briefly ~~some of the~~ major accomplishments.

We have developed and are now expanding a solid management capability for the conduct of research activity. The Space Task Group—and soon the Manned Spacecraft Center—with a very large cooperative and support organization composed of a sizable segment of the Defense Department, civilian industry, and scientific and research organizations, together with the National Aeronautics and Space Administration, now represents a major management resource.

Under the direction of the management team, we have selected and have now verified *in flight* the design of the MERCURY spacecraft.

We have selected a family of launch vehicles with which to carry on our flight program. The LITTLE JOE solid rocket—conceived, designed, and produced specifically in support of MERCURY—has performed yeoman service and gives promise of good growth potential. The REDSTONE was selected for qualification flight tests of the MERCURY craft and its systems in space and for early flight experience by pilots. Finally, the ATLAS gave us early research-flight experience and performance of the specified manned orbital flights.

We have developed and expanded industrial know-how and capacity for the design and manufacture of very complex spacecraft and related systems. The McDonnell Aircraft Company is the prime contractor on our MERCURY spacecraft. It has developed a number of new techniques and processes which should have broad application, not only in the future manufacture of spacecraft but in many other areas as well.

A progressive program of flight operations has been drawn up

and is now well underway. This, of course, involved the development of new launch capabilities and techniques. New ground rules on such things as flight safety and crew protection have been evolved. Ground crews have been recruited and trained in these operations. We have flown many MERCURY spacecraft in many different kinds of tests. Included in these flights were those of two small rhesus monkeys; two friendly and now-famous chimpanzees named Ham and Enos; and two friendly and now-famous fellows named Shepard and Grissom. These, of course, were followed by the now-historic orbital flights of Glenn and Carpenter.

An earth-girdling network has been built for tracking, collection of data, and flight control. Aside from the very complex technical problems involved in the development of the network, there have been some extremely knotty international problems. Further, and perhaps most important, the MERCURY program has certainly accelerated recruitment and training of the skilled people it takes to operate the network successfully. I might add here that I sat in the viewing room of the MERCURY Control Center at Cape Canaveral on September 13, 1961 and watched a magnificent demonstration of skill and teamwork as that network operated in an actual orbital flight situation for the first time. The mission, MA-4, and the exercise of the network, were highly successful.

Last, but certainly not least, we have developed a pool of trained space pilots. The seven original MERCURY astronauts represent a vitally important resource upon which we can build in support of our more ambitious flight undertakings. As we proceed with these new undertakings, we will be selecting and training additional crew members and will be relying very heavily on the skill, knowledge, experience, and dedication of these seven pioneering men.

All of this experience and capability is now in existence. We as a nation are confronted with a new and tremendously more complex challenge, spelled out by President Kennedy before the Congress on May 25, 1961. It is the goal, to be accomplished in this decade, of sending man to the Moon, accomplishing a successful landing on the Moon, and returning to Earth.

Aggressive steps have already been taken in moving forward to meet this challenge. These involve accelerated research on the technical problems, expansion of our management capability, expansion and in some cases literal creation of new resources, such

as research, fabrication, and launch facilities, and build-up of the industrial capability required.

The manned segment of the lunar-landing program is known as Project APOLLO. I would like to underscore here that APOLLO is only the *manned* segment. It is by no means the only project involved, nor can we accomplish the desired end result alone. The NASA-JPL lunar sciences program, including Projects RANGER and SURVEYOR, is essential to the manned lunar-landing operation. Many of the other space research efforts being conducted by NASA, the military, and supporting scientific and educational institutions will be of vital importance to the successful achievement of the APOLLO mission.

As a step toward the three-man APOLLO mission, we feel that considerably more manned-space-flight experience is desirable. An expanded program of manned orbital flights in MERCURY-type spacecraft would give us much-needed launch experience, more knowledge in depth about manned inputs into these kinds of systems, and, in particular, answers to questions about manned operations in space during rendezvous, midcourse trajectory changes, and similar sets of operational experiences. The project name assigned to these flights is GEMINI. This kind of activity will be undertaken concurrently with and in support of our work on APOLLO.

The mission of APOLLO is threefold, as shown in Figure 9. First, we will undertake extended-duration earth-orbital flights; then we will proceed to circumlunar exploratory flights; and finally we will go on to lunar landing and return.

The detailed configuration of the APOLLO spacecraft has not yet been completely defined. Its design will be determined in part by North American Aviation, the prime industrial contractor, and more completely by subsequent NASA-contractor detail design work. Basically it will consist of a three-man command module attached to advanced propulsion modules for lunar landing and take-off. The launch vehicle will be a large multistage chemical rocket of the SATURN C-5 or, possibly, NOVA class.

Project APOLLO began late in 1959 when a small team within the Space Task Group was set up to define the mission and to develop working guidelines. All of the NASA research and space-flight centers and resources were brought into the program to insure that sound basic research would get underway. An intensive in-house design study was undertaken by the Space Task Group dur-

ing 1960, and three industry teams were later brought into the effort to conduct design feasibility studies.

These industry studies resulted in a NASA-industry technical conference in which all of the American aerospace industry had the opportunity to learn the principal results of the research and design efforts and to be brought up to date in preparation for an industry-wide competition for the spacecraft prime contract. This

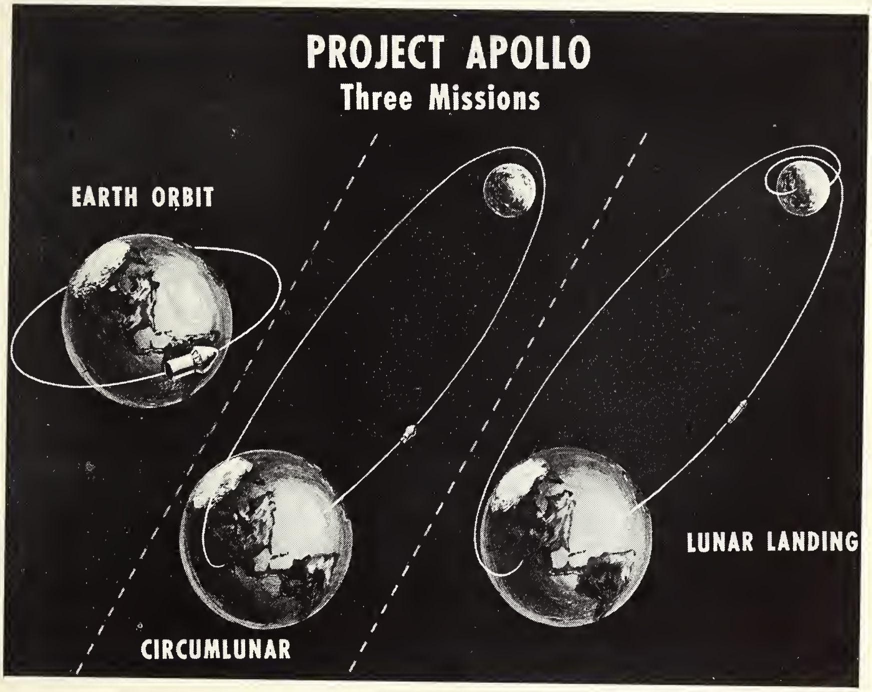


Figure 9. The Project Apollo three-step program.

competition resulted in firm proposals from five major industrial teams, and the contract was finally awarded in December 1961 to North American Aviation's Space and Information Systems Division.

The primary propulsion systems for launching APOLLO are under study. The first stage of SATURN C-1, the predecessor of C-5 and NOVA-class rockets, has already been flight-tested at Cape Canaveral.

To sum up, much of the basic research for APOLLO has been

done, design studies have shown that the project is technically feasible, the prime spacecraft contractor has been selected, and the mission of a lunar landing and return has been recognized by the President and the Congress as an essential national goal. In pursuit of that goal, NASA has provided a management structure for the project, establishing a permanent home for the Manned Spacecraft Center near Houston, Texas.

As in any major advance in technology, a multitude of complex problems faces the project. I cannot go into these problems in detail, but I would like to outline *some* of the major problems.

1. Re-entry Dynamics. The spacecraft and its crew must be protected from the searing heat of re-entry at velocities of 36,000 feet per second. The craft will have to dissipate a kinetic energy per pound of weight that is far greater than the chemical energy of any known compound. However, we can foresee solutions for this by extension of the re-entry technology that has been built up during the past decade.

2. Earth Landing Capability. These problems include the avoidance of local hazards and control of the final touchdown point. Some degree of lift ability in the vehicle itself, plus adaptation of either steerable parachutes or the Rogallo Kite (paraglider), may provide the solution.

3. Lunar Landing. We must achieve a genuinely soft, controlled landing in a vacuum and on a surface about which we know almost nothing. The Lunar Sciences program should provide us with many of the answers we need here. However, a large engineering undertaking will be required in the final solution. There are also major problems in vehicle performance and reliability, including participation of the human crew.

4. Performance. This problem depends basically on the size of the step to be taken. Project MERCURY requires a launch vehicle capable of putting about one and a half tons in low earth orbit. For the lunar landing and return, we will require a launch vehicle capable of putting more than 100 times that weight in low earth orbit. For flights to the moon and the planets, the ratio of take-off thrust to spacecraft weight would approach 1,000 if chemical rockets were used. Because of the extremely large size of the launching vehicle this would require, it may well be that rendezvous techniques will provide the only means of accomplishing the mission, using launch vehicles of considerably smaller proportions. It also seems

clear that we shall soon have to progress to the more exotic forms of propulsion, such as nuclear or nuclear-electric, if we are to engage in planetary exploration with relatively reasonable payload-to-weight ratios.

5. Reliability. Many factors tend to mitigate against high reliability in the design of large space vehicles. But one factor—man—requires that the reliability must be high. We must achieve an order-of-magnitude reduction in failure rates in our launch vehicles to approach the reliability necessary for manned flight. Possibly the desired reduction in failure rates can be achieved by order-of-magnitude increases in previously used measures of simplicity, redundancy, quality control, and human input to control the system. This will not be an easy task, but it is worthy of our most intense efforts.

These problems of Project APOLLO cover a large part of the spectrum of what is now known as space technology. The solutions will without doubt contribute markedly to the general store of technological information and capability, and their effects will be felt in many fields outside the realm of space projects.

I am personally confident that the problems will be solved. But in these times of accelerated technological progress, I have become increasingly concerned about the lack of understanding of the nature of the research we do in the National Aeronautics and Space Administration, and its relationship to other development and engineering undertakings.

Historically the National Advisory Committee on Aeronautics, the predecessor of NASA, conducted what was in essence basic research, though I recognize that I am stretching the common scientific definition of basic research. We did extremely important aeronautical research. We did not engage in broad development work. That phase of our national technology activity was left, or I should say presented, to civilian industry and the military for specific application.

To my mind our situation is no different today. We are using different tools and in many cases different techniques. For example, Project MERCURY is conducted to investigate man's capabilities in the space environment. I feel certain that the civil air-transport industry, if it wishes, will be able to come up with future applications of the knowledge acquired in MERCURY for supersonic flights or still higher speeds. Similarly, if the defense establishment, in

fulfillment of its role as an instrument of national policy, determines that it must carry out missions in space, it will certainly develop such applications.

Manned exploration of space is coming of age. We have now achieved manned orbital flight in Project MERCURY. The creation of this project has proved to be a wise move and has already paid many dividends.

NASA has now undertaken to reach the goal of a lunar flight by funding the program, by including manned space flight as a major element within its headquarters organization, and by establishing the Manned Spacecraft Center. Project APOLLO is well underway. It is now ready to enter the detailed engineering and design phase within the aerospace industry. The first of the large launch vehicles on which APOLLO will depend has already been flight-tested several times at Cape Canaveral.

I think we are all in solid agreement that we have the technical capacity to accomplish these extremely difficult and complex tasks. Admittedly there may be some divergence of opinion within the scientific community regarding which steps to take at which times. But, I'm not sure that these differences don't really work for more healthy technical growth.

An extremely important factor must accompany technical capacity, and that is national will. Besides contributing the best thought we can to solving the technical problems as efficiently as possible, each of us bears a responsibility to help in the development and expression of that national will. We look to the entire scientific, engineering, technical, and industrial fraternity for support in this vital area so that we can proceed at a pace limited only by our technical capacity.

GENERAL DISCUSSION

PICKERING: In connection with the communication-satellite problem, how seriously do you regard the circuit-time delay that occurs in telephone conversations relayed by satellites?

PIERCE: There is a telephone demonstration in existence in which you can hear both time delay and a phenomenon called "echo suppression." We have some experience with the time delay, but there is still the question of the echo suppressor, which is needed to turn off the outgoing voice when something is coming in. One of the difficulties here is that it must be made possible for people to talk without getting cut off.

This problem depends a good deal on the temperament of the speaker. We ran a number of tests with echo suppressors and found that with a delay of 6/10 of a second for the round trip (expected for 24-hour satellites) about 30 per cent of the calls were regarded as not of satisfactory quality. However, some subjects *always* ob-

jected to the time delay, while others *never* did. Actually there are some people who have difficulty with *any* type of conversation. In telephony, however, we generally have to satisfy not 70 per cent of the people but something over 95 per cent, because people who are dissatisfied may complain. There are a lot of telephone users, and a very small percentage of them can constitute a lot of people.

I do not regard the time-delay problem as very urgent at this time, since practical satellite communication is a number of years away.

PICKERING: Dr. Friedman, in considering the scientific problems to be solved in solar system physics, do you regard it as very important to have simultaneous measurements conducted, say, from the surface of the earth, from near the earth, from somewhere in the earth's orbit, and from somewhere out of the plane of the ecliptic? In other words, do you foresee a time at which we are going to want to have a system of space probes, satellites, and earthbound space observations all tied together?

FRIEDMAN: The answer to part of that question is very direct. We have tremendously well-developed resources for observation from the ground, but these resources, in the case of astronomy, are limited to the optical window and the radio window. When we can conduct simultaneous measurements from observatories in space, we are able to observe, in addition to the X-ray and ultraviolet radiation spectra, those portions of the radio spectrum that cannot penetrate the ionosphere. This greatly augments the value of data that can be accumulated from the ground. I can foresee that we would also require intermediate steps to complete the picture. If we are concerned with solar-terrestrial relationships, for instance, we want to know not only what the sun is doing, but also what other effects associated with solar activities are taking place. These associated effects occur throughout the range of the atmosphere and the interplanetary medium.

REICHELDERFER: The TIROS satellite has been designed for a life of three to six months. Are there serious problems in extending that life to a year or so, or can we be fairly optimistic about improvements in the operational life of satellites of this kind?

PICKERING: This problem of satellite life is certainly of great interest

for almost all satellite applications. As Dr. Kantrowitz pointed out, it costs a lot of money to put these few pounds up into space, and we would like to exploit them as much as possible. Dr. Pierce has stated that communications satellites, to be practical, will require a lifetime measured in years. This is the case also for planetary missions and for other types of satellites. Therefore a large technological effort must be devoted to assuring that we obtain long-life satellites.

We have had remarkable success with some simple devices. For example, VANGUARD I, launched on March 17, 1958, was still transmitting in 1962, and EXPLORER VII, which was supposed to turn itself off after one year, failed to do so and was still transmitting in 1962. Of course, there is a considerable difference between their relatively simple transmitters and the complex gear we are now considering, but having even these simple devices work over such long periods is encouraging.

Pierce: There are two sorts of failures in satellites. Some things —*e.g.*, resistors, capacitors, and transistors—fail in a random manner. They don't *wear* out. Solar cells tend to wear out because of radiation, but if they are designed to allow operation at, say six-tenths of the peak attainable efficiency, they can last for many years, even in the middle of the Van Allen belt. Storage batteries at the present time are fallible, but I believe we ought to be able to do something about that.

Transistors, resistors, and capacitors developed for consumer use certainly would not last for long periods of time. But the Bell Laboratories and our military programs have developed transistors and other components so reliable that, if treated properly, a given thousand components may be expected to last for at least one or two years.

Friedman: As a space scientist I find it a traumatic experience to have one of my experiments carried by a vehicle that fails. We are not always able to duplicate or repeat that experiment on the next vehicle. What are the prospects of getting vehicles or programs guaranteed to continue to carry our experiments until they succeed?

Pickering: This is a difficult problem, obviously. It has been with us ever since the early days of the IGY satellite program. At that time, it was expected that only a very few pounds would be put

into space, and therefore only a small number of experiments could be programmed. Further, the chance of success was low. All I can say is that the people who have to determine in advance the ultimate value of the experiments which are placed on each of these probes (this is done by the scientific office at NASA) try to select what looks like the best sets of experiments available which are compatible with a particular probe. However, it is quite clear that the weight of our spacecraft is increasing rapidly, and I hope that the opportunity for performing experiments will increase accordingly. I am afraid that for the time being we will just have to hope that the next shot will be a good one!

> QUESTION: Direct nationwide TV broadcasting by satellite will require about 25 kilowatts per channel over the United States. Would you say that we will be capable of providing such powerplants in the near future?

PIERCE: The only useful application of direct television broadcasting from a satellite that I have heard of was suggested in a story by Arthur Clarke. It was put to use in that case to undermine the morale of the United States by means of indecent broadcasts originating on the other side of the Iron Curtain!

Actually the fact of broadcasting life is that most programs in the United States are local—local advertising, local news, and local weather. I don't think the television broadcasters or television audiences would like to have their programs all coming from the same place with the same weather, the same news, and the same advertising. I think the way to worldwide television is to send programs by satellite to local areas where the programs can be put in the language and context that best apply to that area. It would be wise for those who are thinking about this type of television broadcasting to make a low-powered satellite first, in order to examine the problem and see what the difficulties are.

As far as I know, no one is developing long-life, high-power transmission equipment for satellite broadcasting of television, although some preliminary ideas have been put forth as to how this could be done. I think the high-powered satellite is an admirable thing to work on, because it has many applications, but these seem to be restricted to the rather far future.

Question: Is a large manned-satellite laboratory now being planned by NASA and, if so, for what reasons? Since some "insurance" in attaining early success of APOLLO is of great national importance, has any alternate technical approach been considered for development as a backup for the existing APOLLO approach? Orbital assembly, for example, appears feasible, but what if it isn't?

Gilruth: There is now a plan for a manned space laboratory. It is not a firm plan; it is not going out for contracts. As an adjunct to APOLLO, a space laboratory is planned for long-duration studies, probably within the next decade. It would probably be launched as a unit, rather than be assembled in orbit.

The answer to the "alternate--technique" question is, of couse, definitely "yes." We can do things with rendezvous techniques, both weight-wise and vehicle-wise, that we can't do with the direct approach, provided we can make good on the delicate rendezvous operations. I pointed out that one principal APOLLO concept has recently switched over to the rendezvous technique, in order to bypass the greater costs of the NOVA-class booster that would otherwise be required. The big booster is, of course, being maintained as a backup in case the rendezvous operation should prove too difficult.

Kantrowitz: You have pointed out that the rendezvous technique can make a tremendous impact in decreasing the time necessary to get our man to the Moon. What are we doing to establish whether or not we can *depend* upon rendezvous for simplifying this mission? When will we try rendezvous experimentally?

Gilruth: The kinds of study that have been going on relative to rendezvous, of course, have been those which have to be done first to show the potential for such a maneuver. Many problems are involved in this technique, and they are not all launch-vehicle and guidance problems. These fundamental problems apply not only to rendezvous but also to getting out of the spacecraft on the Moon so that our men can do useful things when they get there.

In the best spacesuit available in this country today, the body is about as immobilized as if it were inside a low-pressure tire. Fur-

thermore, if the suit were punctured, the effect in space would be disastrous. In other words, the personal equipment problem, in my opinion, is one of the very important problems that has yet to be solved. We are going to need not only medical minds on this but also engineers to figure out the best way of equipping a man so he can work in a hard vacuum. The Moon travelers will need to do useful work, such as coupling machines together, repairing things that may have gone wrong during the launch, getting the vehicle ready for the next step, and so on, in addition to the lunar operations themselves.

KANTROWITZ: Do you have the feeling that we will learn a great deal about the difficulties of the problem you mentioned by means of "paper" studies? It seems to me that the emphasis on paper studies is a little hard to justify. These rendezvous problems have to be studied in a more practical manner.

GILRUTH: I think most of the paper studies have already been made. Quite obviously a lot can be gained from these studies, but we have to get on with the hard plans to actually perform these tasks and find out what are the practical problems involved.

QUESTION: Has much thought been given to methods of returning lunar-surface samples to earth? Is any *action* being taken on a sampling program?

PICKERING: This is a very interesting question. Before we try to send a man to the Moon and return him, it might be advisable to send up a vehicle which can pick up a rock and bring it back. One of the tests visualized is a sample-return project: mechanisms will pick up a sample, put it inside a rocket, screw the case shut, and fire the rocket back to Earth. We will then go out into the desert where it falls and pick it up. This aspect is quite a fascinating problem in itself, when we compare it with the problem of trying to find a lost airplane. How do we find a sample of rock from the Moon? This whole problem of sample-return is being given a lot of thought.

QUESTION: Have landing missions to the asteroids

been seriously considered? If so, can you briefly discuss their advantages and disadvantages compared to planetary landings?

Pickering: In the exploration of our solar system, the most interesting immediate targets appear to be Mars and Venus. Beyond these two, we might go in a number of different directions. One, of course, would be expeditions to a more distant planet—Jupiter or Saturn. Another would be a flight outside the plane of the ecliptic, to look at the solar system from that angle and particularly to observe the sun itself.

I do not know whether any serious thought has been given to actual landings on the asteroids. I suppose if one could land on the Moon or on one of the planets, landing on one of the asteroids should not be much different. However, I believe that by far the most interesting thing to do first is to land on either Mars or Venus.

Kantrowitz: I wonder why you consider that definitely more interesting? It might even be *easier* to land on one of these asteroids, because they do not have much gravity. Further, they do have a history similar to that of the planets, so that many of the same sort of scientific questions might be answered by landing on one of the asteroids.

Pickering: It is true that landing on one of the asteroids is simply a rendezvous problem, and one could presumably accomplish it. I think the question really is whether or not an asteroid is a piece of meteoric material. I grant you that it would be an interesting thing to do, but I'd rather go to Mars or Venus first. I believe we have a lot more to learn there.

Question: Would you discuss other missions that could have commercial applications and could therefore enjoy commercial financing, as well as tax financing, during early development stages and launching?

Pierce: I may be plain and unimaginative, but I cannot think of anything aside from communications that seem to have commer-

cial possibilities. Weather forecasting is, of course, a practical possibility, but throughout history this has been a non-commercial enterprise.

KANTROWITZ: It seems to me that we have looked for applications which require only extremely light-weight equipment, because of the tremendous launching problem. I believe, therefore, that we will have to wait for a substantial reduction in launching costs, or a substantial improvement in our imagination and inventiveness, before we can come up with other obvious commercial applications.

QUESTION: Please comment on the Russian announcement casting doubt on man's effectiveness when exposed to weightlessness for extended periods.

GILRUTH: I suppose you are referring to the discussion of Titov's 18-orbit flight, during which he was nauseated at times. It is very difficult for us to assess what this means, because of several factors. First, this type of experience, as we all know, may be related to the individual involved; we know that some people get seasick and some don't under the same circumstances. Second, the Russian astronauts are considerably younger and less experienced than the pilots we selected as most suitable for our initial space flights. Our flights to date have been admittedly of shorter duration, but our men have not experienced any sickness as yet. Third, we don't know enough about the Russian spacecraft's life-support systems; *i.e.*, the degree to which the cabin air was kept pure and viable, and so on.

Many other factors besides the weightlessness itself may have caused Titov's difficulty. I am not ready to assume that we must scrap our plans for weightless flight and try to make all our spacecraft into gigantic merry-go-rounds to provide artificial gravity. Of course, I would expect that some physiologists and doctors may look at the problem quite differently from the way I look at it.

QUESTION: The temperature of Venus' atmosphere was recently reported to be as high as 600° Fahrenheit. Have lower temperatures also been encountered? If so, what magnitude?

Friedman: The 600° temperature is based on measurements of the radio emissions of Venus. The question being debated is whether this represents the temperature at the surface of the planet or somewhere in its very dense atmosphere or ionosphere. I think the majority opinion is that this is truly the temperature at the surface. One of the theories is that the Venus atmosphere is filled with dust, and that the high temperature at the surface is a result of the friction of this windblown dust on the surface.

Question: When lunik i hit the Moon, did it vaporize or dig itself in the dust layer? Please comment on the thickness of the dust layer on the Moon.

Friedman: Of course, nobody was there to see lunik i! We used to consider the possibility that the dust on the Moon might be miles deep, and that landing objects would sink out of sight immediately in this quicksand of loose dust. Most of the evidence now available, however, seems to point to a rather thin dust layer. In fact, some recent observations of the spectral emission from the lunar surface during the course of an eclipse can be interpreted in terms of a dust layer about half a centimeter thick, superimposed on another much coarser layer perhaps several centimeters thick, resting on top of a rocky layer.

Question: Does the panel have any opinion as to why the Russians to date apparently have not paid too much attention to application satellites?

Reichelderfer: I have asked that question each year in meetings with Russian delegates who come to Geneva for the World Meteorological Organization. They were quite unresponsive for the first year or two, but at the last meeting they seemed to be more responsive. However, their reply is still that the U.S.S.R. has been giving attention to other programs. This implied to me that they thought the race for distant goals in outer space was more important than applications in meteorology.

Pierce: The Russians, occupying a wide expanse of continent, perhaps have less use for communication satellites than we do. We

need to be in touch with Europe, Japan, South America, and Australia, which have very poor communications.

FRIEDMAN: The Russian program of space science seems to be guided in certain well-defined directions. It shows great concentration on measurements of the conditions of the interplanetary medium—conditions which would determine communications with deep space probes. There is also a concern with evaluating the ionosphere of a planet like Venus, which would be of the greatest importance in getting data back from a mission to Venus. These things certainly indicate that they put a very high priority on the goal of interplanetary exploration.

KANTROWITZ: I think that the fact that we have made more progress than the Russians in actual application of satellites is only one more evidence of the vast technological base we have in this country. These application satellites require help from other areas of technology which are much weaker in Russia than they are here, and it is therefore reasonable to expect that they would lag somewhat behind us in this area.

II. The Vehicles

EDITORS' INTRODUCTION

A SPACE VEHICLE consists of a rocket engine, a tank or tanks to hold the propellant fluid, a guidance and control system, a "payload," and a structure to hold these parts together.

Although we normally think of a space vehicle as one complete system, it is actually composed of two separate entities: (1) the "booster," and (2) the true space vehicle or "spacecraft." Each performs its function at a different phase of the flight.

The booster is required to lift the vehicle against the pull of the Earth's gravity. It lifts its payload off the earth until it either escapes completely or goes into orbit. Because of the enormous energy needed for these tasks, most of the booster's weight is made up of its engine, tanks, and propellants—collectively called the "propulsion system."

When the vehicle has achieved its desired trajectory, whether it be an escape trajectory or an orbit around the earth, the empty tanks and engine of the booster are usually discarded. The remain-

ing payload, coasting in its trajectory, is now called the spacecraft.

Some of these space vehicles simply remain in orbit and do not need any further propulsion. Others carry their own propulsion systems and may undergo further maneuvers, such as a flight to the moon, a flight to other planets, or return to the Earth. Since the spacecraft usually needs far less energy for travel in space than for escape from the Earth's gravitational pull, this propulsion systen is generally a much smaller fraction of the vehicle's overall weight than that of the booster.

The United States' early efforts in space were concentrated on the booster problem. Today it still remains a major limitation on our space effort, but boosters are now considered the less interesting part of a space vehicle—mere "trucks" used to take up payloads. The main attention has shifted to the myriad tasks the vehicle is expected to perform.

As our missions grow more ambitious, our overall vehicle concepts become more complex, and the machinery necessary to perform space missions is becoming more sophisticated. This section is devoted to a critical examination of our swiftly developing state of space technology in terms of the vehicle and the problems encountered in creating our newest mode of transportation.

Mr. Ehricke comments on how the current technical and sociological milieu has affected space-vehicle research. Mr. Hawkins then outlines the overall engineering problems of spaceship design. He focuses on the paramount technical problem in space vehicle operations—the reliability of the vehicle.

The most critical aspect of the vehicle is still its propulsion system. Dr. Summerfield discusses the history, the development, and the progress made by the types in use today—the so-called "conventional" chemical rockets. These derive their energy from the combustion of propellant chemicals, usually a fuel and an oxidizer.

Dr. Bussard considers the future of propulsion technology and suggests the kinds of improvement we may look for. He discusses the possible use of nuclear energy to power entirely new classes of rocket engines, and describes the principles of several of these "advanced concepts." They range from direct application of the heat from a nuclear reactor to the conversion of nuclear energy into electrical energy. Dr. Bussard concludes that nuclear power will

be necessary for really difficult missions, such as manned flight to the near planets or any trip to the far planets.

Dr. Draper views the historical background and present status of guidance systems and their components. These include not only the devices that give commands to the engine or steering apparatus to keep the vehicle on course but also the steering apparatus, the equipment needed to determine the position of the spacecraft at any time, and the instruments that tell how fast it is going and in what direction.

Dr. Debus outlines the United States plans for launching the large booster rockets essential for lunar flights and large satellites. These launchings are centered on a completely new philosophy of launch-pad operation. Dr. Debus points out some of the shortcomings of the system now in effect at Cape Canaveral and suggests how they can be rectified by using the new launch system.

Mr. Dow highlights three major problems in the development of our space flight program: (1) protection of spacemen from natural radiation in space, (2) re-entry into the atmosphere without burning up, (3) the "rendezvous problem"—that is, the problem of bringing two, three, or more vehicles together in space. The progress and success of our space program hinges on how we solve these three problems. Mr. Dow suggests that new ideas and new approaches are necessary for the resolution of these problems.

PROLOGUE

KRAFFT A. EHRICKE, *Director of Advanced Studies, General Dynamics Astronautics*

At the present time I can think of hardly anything more important to the space-flight program than the development of space vehicles. First we will need them to carry the instruments out into space, and later we will need them to carry men safely and reliably to other worlds.

Before considering technical details, let us set up the framework of how we think of a space vehicle. Philosophically we may compare the importance of the space vehicle to the importance of the development of the egg in the history of life. As life emerged from the marine environment into the extramarine environment, the egg became all-important. Animals achieved independence of the sea only after the embryonic young, the egg, developed a tough shell which protected life in its initial tender phase from a thoroughly hostile environment.

As we take the next big step in expanding life from terrestrial to extraterrestrial environmental conditions, the "egg" of our time—the space vehicle—is needed to carry man out into space and eventually to help him drive roots into other worlds for permanent forms

of existence. This existence may be very different from our present one, but it will still be a human existence, sparking new reactions and new civilizations in the course of the centuries.

Let us consider the practicalities of space-vehicle sizes, weights, and other characteristics. We have found that manned orbital flights call for big payloads, *i.e.*, 10,000 to 20,000 pounds for even modest operations. For lunar landing, again on a modest scale, we will have to start out with weights in "parking" orbits around the earth of the general order of 200,000 to 250,000 pounds, or, if we can achieve early development of nuclear rockets, perhaps only of the order of 150,000 pounds. For even modest planetary investigations, such as reconnaissance flights to Venus or Mars and back, we shall have to have an initial weight in Earth orbit of the order of 1.5 to 2 million pounds, or perhaps as low as 400,000 to 500,000 pounds if we use a nuclear-electric propulsion system. These are enormous payloads by present-day standards, even if the vehicles are put together by rendezvous of the parts in space.

The economics of the vehicle is an important factor, because we cannot, in the long run, throw Earth-to-orbit vehicles away after we have used them once. We will have to re-use them. For this reason, and because it is necessary to keep the size of the vehicles in manageable proportions, we are pushed more and more toward high-thrust nuclear propulsion. There appear to be two types of nuclear powerplants that will satisfy long-term booster requirements. First is the nuclear heat-exchanger system, not necessarily in its present form but probably in a more advanced form with higher specific impulse. Second, and perhaps even more important, is the nuclear pulse-type system, such as the ORION vehicle, which operates on the basis of explosive release of fission energy. Perhaps we may eventually develop powerplants based on fusion energy in compact form. Any of these systems should provide sufficiently high thrust to carry up enormous payloads and return. However, just as on the Earth we have a range of transportation running the gamut from bicycles to jet planes, in space we will have to rely on a range of transportation running the gamut from our present chemical systems to big nuclear-pulse or nuclear heat-exchanger systems. The choice of system will depend on the loads we want to send into space and their missions.

Spacecraft, especially manned space vehicles, also require a departure from old-fashioned concepts of minimum-energy flights

and safety margins. They call for an almost religious adherence to the principles of simplicity, reliability, standardization, and exchangeability, even at the expense of payload-to-gross-weight ratios. The spacecraft also require larger and larger launch complexes, bigger investments, and, in many respects, new approaches to checkout and launch safety.

We must also consider more carefully each phase of orbital operations. There are three primary phases: (1) orbital departure after assembly, (2) orbital rescue, and (3) landing and takeoff from other celestial bodies.

Orbital rescue is especially important when we have people aboard. We want to avoid having to say, "Well, that was just tough luck," and give the crew's families big insurance checks while their men slough around in some eccentric orbit between Mars and Jupiter. We want to be able to get them back.

Finally, landing and take-off operations on other celestial bodies will have a greater and greater influence on the design of the Earth-launched space vehicles.

Although most of our problems are ultimately concerned with manned space flights, these will be spearheaded by flights which carry only instruments. We need these instruments in order to explore space and to determine certain specific requirements, such as protection against radiation belts and solar flares. Furthermore, we need unmanned space vehicles to develop vehicle components to a high state of reliability and maturity, since those same components will later be used in manned spacecraft.

At present we are in the transition from missiles to spacecraft. We are still using missile-type boosters, and will probably continue to do so for quite some time. The CENTAUR booster is an excellent example of the transition. Its upper stages have already begun to shape up more distinctly as space vehicles, in that they use high-energy propellants and restart techniques such as were originally used with the AGENA. The upper stages of SATURN, in various forms, will follow suit.

The introduction of hydrogen as a fuel also means an important step toward high-energy propulsion of a different type, namely, the nuclear. All of the presently conceived direct nuclear powerplants need hydrogen, either immediately or in the long run. Thus our first-generation space vehicles, based on the hydrogen-burning

CENTAUR, lead us into the more advanced types of powerplant necessary for future large-scale space operations.

I would like to recall that the prehistoric prototype of our space vehicle—the egg—has a mass ratio (percentage of expendable contents) somewhat better than that of the best current rocket systems—about 93 per cent. It is a good idea to keep this in mind as we look to our advanced space-vehicle design problems.

6 SPACE VEHICLE SYSTEMS

WILLIS M. HAWKINS, *Vice President, Engineering, Lockheed Aircraft Corporation*

It is my purpose to assemble some thoughts on the probable next steps that we must take to create suitable vehicles for the space missions which, for the moment, are somewhat beyond our present capabilities. I shall discuss first the design philosophy, then how this philosophy may affect the payload and booster systems, and finally a few conclusions that may be useful.

In any reasonable design task, the solutions are generally dictated by a series of performance goals and a collection of design limitations. In the case of space vehicles, however, there are unique and important additional factors which must be considered. These have to do with our political and technical environment, which is not nearly as cooperative as the performance goals or design limitations, but may have a major influence on the resulting system.

The main points in our political and technical environment are:

1. We are now enjoying our first successes, but what we have done has been just barely reliable enough to prove first principles.

2. The initiative to decide on what we should do in space, and when, is not yet ours.
3. Dollars are available, but they are turned on and off by public sensitivity to success and failure. At best, the dollars are subject to fluctuating external pressures and are available for only one fiscal year at a time.
4. The vast number of possible space missions suggests little repetition of procedures and hardware from flight to flight.
5. Our knowledge is still so meager as to be nearly nonexistent, and every step we take suggests changes in design concepts for entire systems and most of the elements.

In this environment, what possible philosophy can one have to insure success? Obviously there is no simple solution, but it seems to me that some ground rules are beginning to emerge.

1. Reliability. Man is about to join the vehicle guidance and command loop "on board." This means that we can no longer be satisfied with a 50 per cent to 70 per cent chance of mission success; a "step-function" is called for in reliability and a "100 per cent sure" philosophy must prevail at every creative and/or service level that has anything to do with the space vehicle.
2. Cost. Dollars will be available only spasmodically. All of our new systems should be designed of building blocks so that some of their value can be salvaged if budgets for the larger system are reduced or cancelled. In this way, even though the building blocks are elements of large systems, they will have sufficient utility to be used in smaller systems.
3. Our very real lack of knowledge concerning the space environment, coupled with our accelerated acquisition of new information, guarantees that our first efforts in any direction will be subject to large changes as experiments are conducted. Therefore, the best design approach is to seek a system concept which can accept changes until the last possible moment before use. We should not attempt a precisely optimum solution for new vehicle systems and create too rigid a design. It is now time, it seems to me, not to try to suppress changes but to design systems so that they may be made efficiently.

Now, how do these ground rules affect the payload? It is in the payload vehicle system that the reliability factor predominates.

If we consider man-carrying, planet-exploring systems, we have at least three major reliability categories. I have called them: "get-back" reliability, "long-life" reliability, and "stay-sane" reliability.

With respect to "get back" reliability, we have to consider the fact that maintenance-support and ground-support facilities will be lacking when a man makes an extraterrestrial landing and prepares for the return voyage. Here it appears that the only real solution is multiplicity of systems, giving "multi-engine" reliability

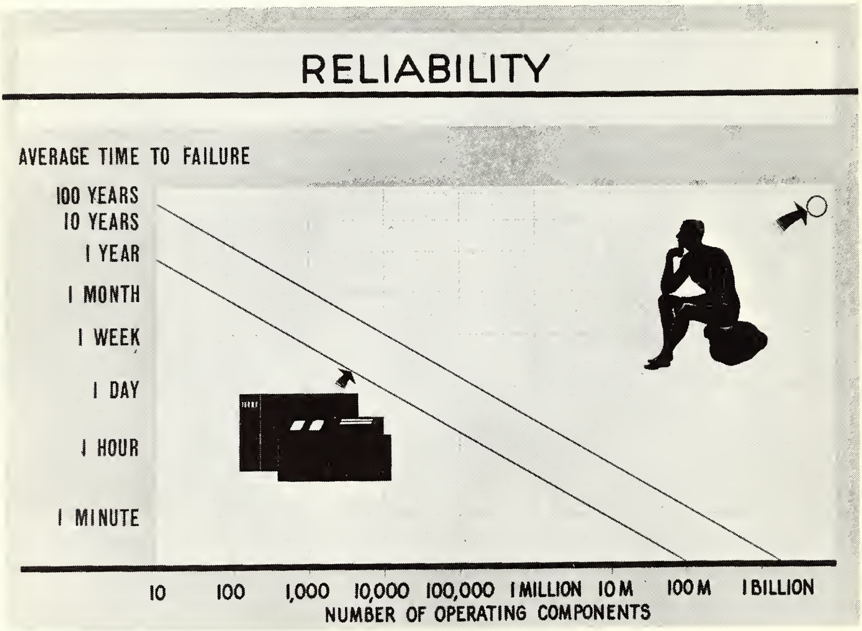


FIGURE 10. The decline in the reliable lifetime of a space-vehicle system with increase in the number of components.

in all critical return systems. This multiplicity of systems is going to cost payload, money, and time, and it will be far from simple to accomplish. Electronic components have multiple failure modes, and a system that will accomplish "healing" in one failure mode may be completely useless in another. Furthermore, one look at the power-distributing systems, the instrumentation lines, and the information lines in a spacecraft will emphasize the switching problems involved in multiple systems, even if we assume that failure modes can be discovered and identified.

One thing, however, is very clear. There is no substitute for a man in failure recognition, identification, and emergency analysis. It still takes the pilot to identify a failing engine on a multi-engine transport and to institute procedures to keep the aircraft safe. Making even this relatively simple emergency situation completely automatic would present some major problems. We can conclude, for "get back" reliability, that man, the impelling reason for requiring a major step-function upward in reliability, will actually help us to make that step by making possible the selection and use of redundant vehicle systems.

When we consider "long life" reliability, an entirely new prob-

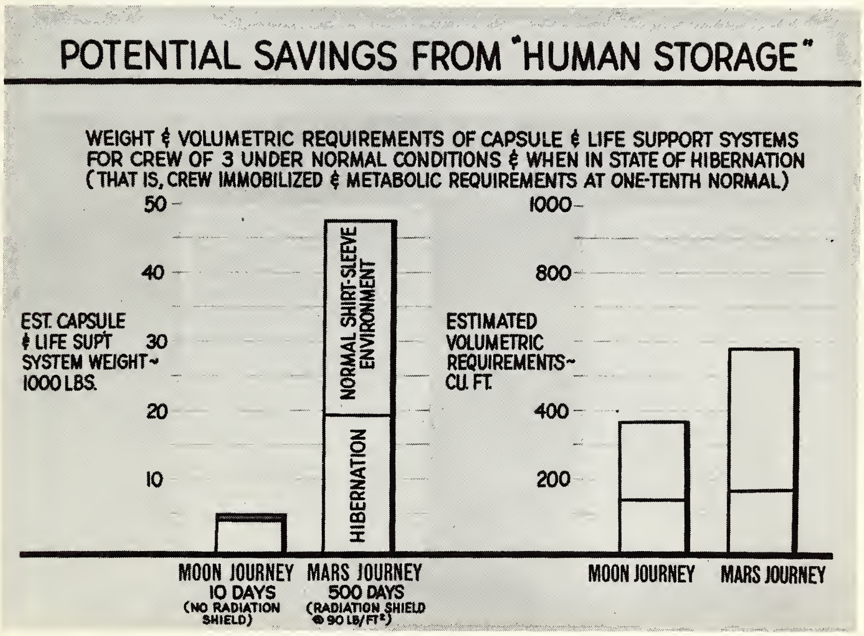


FIGURE 11. The total height of each column represents the weight and volume required if the space vehicle provides a normal environment. Considerably more than 50 per cent in weight and volume would be saved if the crew were kept in a state of suspended animation.

lem faces us. This problem is not of a kind that a man on board can solve; in fact he becomes something of a nuisance, as we shall see. Figure 10 illustrates where we stand in accomplishing this kind of reliability. The broad band is actually an approximation of our ex-

perience. This band suggests that an orbital or space vehicle with a mission requiring a year probably could not have more than 100 critical parts. We cannot afford to accept this discouraging suggestion as a fact, for it would stop our space endeavors. We must continue to try for ground-based test techniques or orbital test methods which will move this "experience curve" to the right. Of some encouragement is the estimate that man himself is made up of more than a billion critical elements but somehow staggers through a rather miserable environment at a frightening pace and still lasts sixty or seventy years.

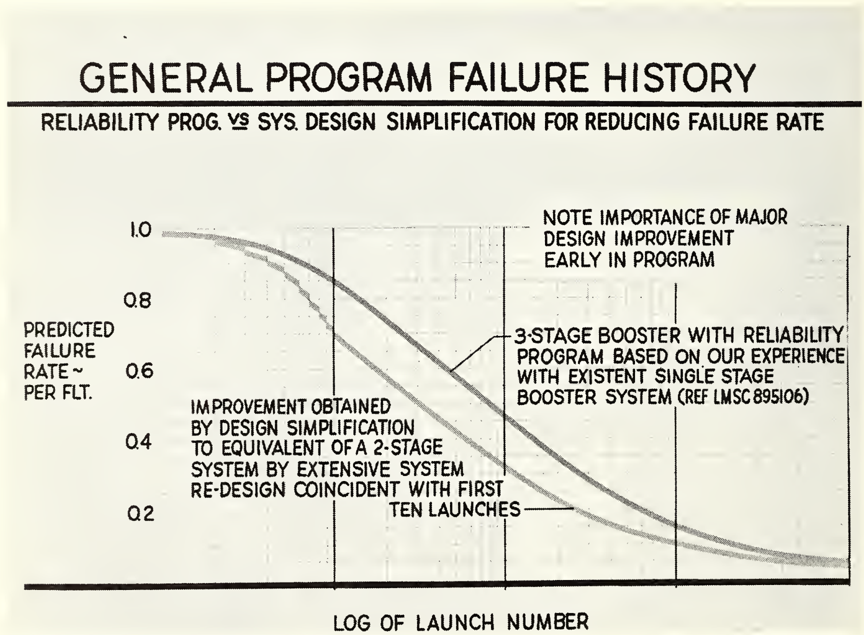


FIGURE 12. Reduction in the failure rate of boosters that might be obtained by simplification of design.

The problem of "stay-sane" reliability applies only to long missions. A trip to the moon, taking no more than ten days, seems to present no particular worries on this score. True, the launch, landing, and return will be strenuous, but man rarely loses his sanity in circumstances of high activity and concentration. It is the mission to Mars that concerns me here (or to Venus, if you prefer). This involves times of a year or more with no activity or responsibility.

No one has offered a real solution for this problem, but since we have to start somewhere, I suggest that in our medical space research we search diligently for an idea which will make possible a "hibernating" man.

I have made some broad estimates of what we might gain by that resort. Figure 11 compares the estimated weight and volume requirements of spacecraft for a crew of three with and without hibernation. The estimated differences are major. But note that the

DIRECT FLIGHT OF LARGE VEHICLE

	UNIT RELIABILITY (1967)	ABORT RELIABILITY	UNIT COST % OF TOTAL
RE-ENTRY	.99		2%
LUNAR TAKE OFF	.95	0	
LUNAR LANDING	.95	.95	
BOOST STAGE III	.85	.95	1%
BOOST STAGE II	.85	.95	2%
BOOST STAGE I	.80	.95	3%

NOTE: THREE LAUNCHINGS FURNISH 0.90 PROB. OF MISSION SUCCESS

PROBABILITY OF LOSS OF LIFE IN ENTIRE PROGRAM = 0.10

COST:	
BOOSTER DEVEL. & TEST	65%
LAUNCH FACILITIES (NEW CENTER)	15
FLIGHT VEHICLES (3 COMPLETE)	20
TOTAL	100%

Figure 13. Estimated reliability obtainable for a multistage lunar-landing vehicle—System A.

weight of the vehicle depends much more heavily on the need for shielding against radiation, which is assumed to be essential for a trip to Mars. This obviously places a premium on keeping down the volume and suggests emphatically that we do all we can to reduce the passengers' volume requirements. Whether we also need to hibernate man to keep him sane I don't know, but I suspect that we need to accomplish at least the equivalent. Certainly we can save pounds and dollars if we do.

Turning to the booster elements of a space system, we may now consider performance reliability in a more conventional manner and try to determine how major improvements can be introduced in a revolutionary rather than evolutionary way. Figure 12 shows the target. It plots predicted failure rates of a three-stage system on the basis of our experience today in producing constantly maturing systems. The unfortunate aspect of this curve is that we cannot afford to make the number of flights that would be necessary

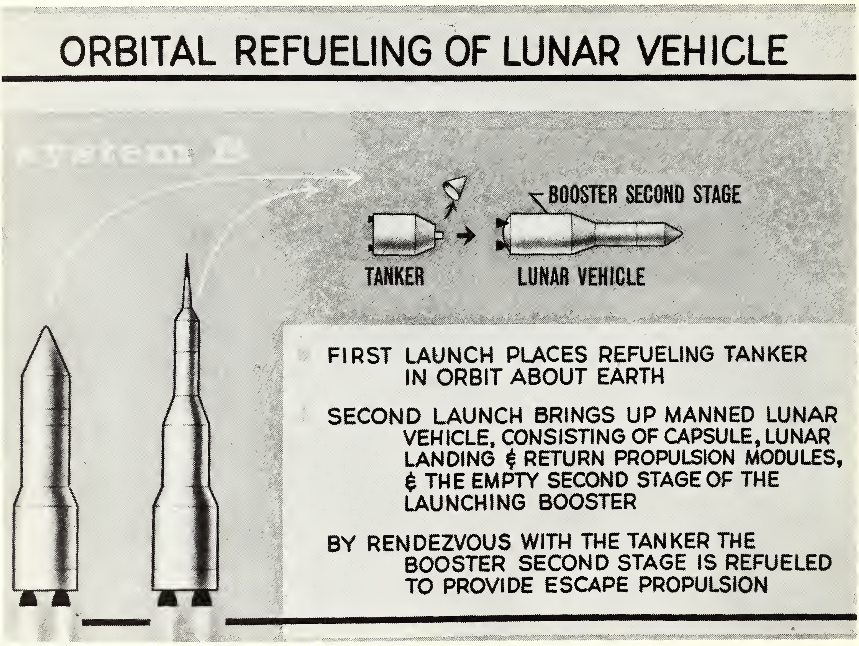


FIGURE 14. Concept of refueling a lunar-bound vehicle at a rendezvous in an orbit around the Earth—System B.

to reduce the failure rate to the minimum, particularly with systems large enough to put manned missions in space. Furthermore, if we did reach this minimum, we would still be many orders of magnitude more vulnerable to failure than are today's passenger airliners. It is obvious that we must continue doing what we can with the component elements of the system, but it is equally obvious that this cannot be depended upon to solve the problem. We need many breakthroughs in simplicity, and we need new concepts of

total systems. The performance criterion of any total system ultimately must be maximum reliability.

I propose to analyze one such system concept in a superficial way, in order to illustrate the reliability results and to point up the building-block concept mentioned earlier.

Consider first Figure 13. This is an example of a hypothetical multistage vehicle system designed for lunar landing and return. Educated assumptions have been made regarding the reliability of

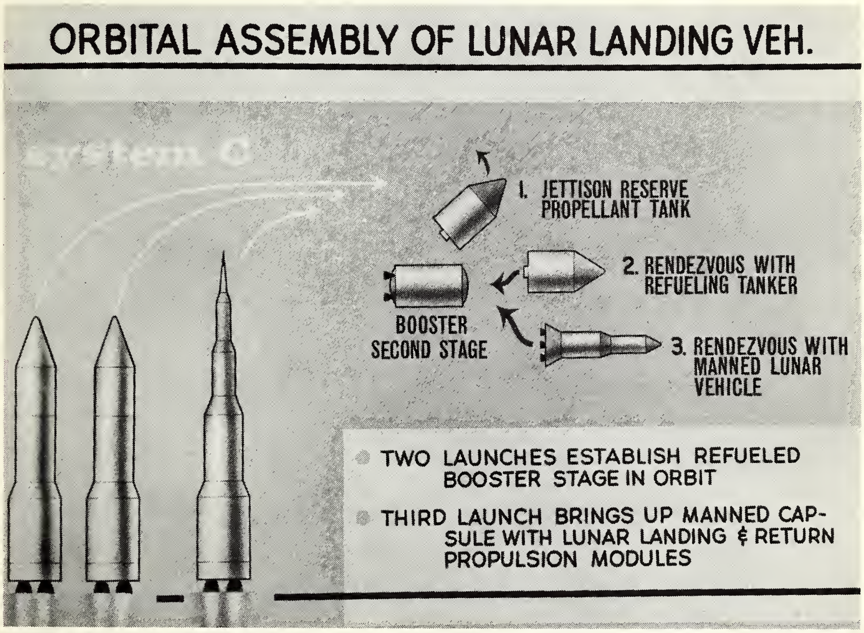
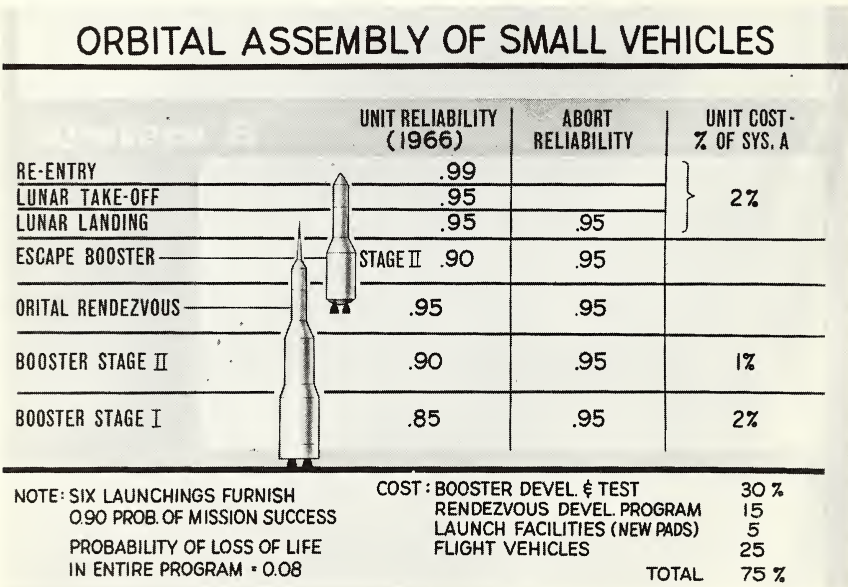


FIGURE 15. Concept of assembling a lunar-bound vehicle in an orbit near the Earth—System C.

each element from the standpoint of completing the mission (unit reliability), and from the standpoint of operating satisfactorily enough to prevent loss of life (abort reliability). In addition, an attempt is made to estimate the relative costs of the booster development portions of the system, the launch facilities, and the actual flight hardware to obtain a 90 per cent probability of success on one mission. It will be noted that, with the assumptions used, a probability of loss of life of 10 per cent exists. This system we have called System A.

System B (Figure 14) suggests another approach to the same mission. The first launch orbits a refueling tanker. The second launch brings up the payload capsule, still attached to the now depleted second stage of the booster. This combination performs a a rendezvous with the tanker, refuels, and proceeds with the mission, having descarded the tanker. The booster system for both launches is only two-stage, and it is considerably smaller than the three-stage System A.

System C (Figure 15) is an alternative approach based on the



ORBITAL ASSEMBLY OF SMALL VEHICLES

	UNIT RELIABILITY (1966)	ABORT RELIABILITY	UNIT COST - % OF SYS. A
RE-ENTRY	.99		2%
LUNAR TAKE-OFF	.95		
LUNAR LANDING	.95	.95	
ESCAPE BOOSTER	STAGE II .90	.95	
ORITAL RENDEZVOUS	.95	.95	
BOOSTER STAGE II	.90	.95	1%
BOOSTER STAGE I	.85	.95	2%

NOTE: SIX LAUNCHINGS FURNISH 0.90 PROB. OF MISSION SUCCESS

PROBABILITY OF LOSS OF LIFE IN ENTIRE PROGRAM = 0.08

COST:	
BOOSTER DEVEL. & TEST	30 %
RENDEZVOUS DEVEL. PROGRAM	15
LAUNCH FACILITIES (NEW PADS)	5
FLIGHT VEHICLES	25
TOTAL	75 %

FIGURE 16. Reliability and Cost of System B.

same principles but aimed toward placing more usable fuel in the orbiting system and increasing the payload available for lunar landing. In this case, the second stage of the booster is launched into orbit with an attached tanker. This launch is followed by a second tanker launch and refueling. Finally, a third launch puts the payload vehicle into position to rendezvous with the second stage, which now has substantially more fuel than is available in System B. This has the purpose of increasing the payload capability over that of both System A and System B. The purpose of the extra pay-

load delivered to a lunar landing is to increase the multisystem redundancy of the lunar landing capsule, thereby improving the "get-back" reliability.

Figure 16 summarizes the reliability performance and the probability of loss of life for the two-launch rendezvous system (System B), along with an estimate of the probable cost relative to the multistage "standard" System A. The numbers, though not demonstrably accurate, are believed to be relatively correct. They show that the rendezvous system is only 75 per cent of the cost of a

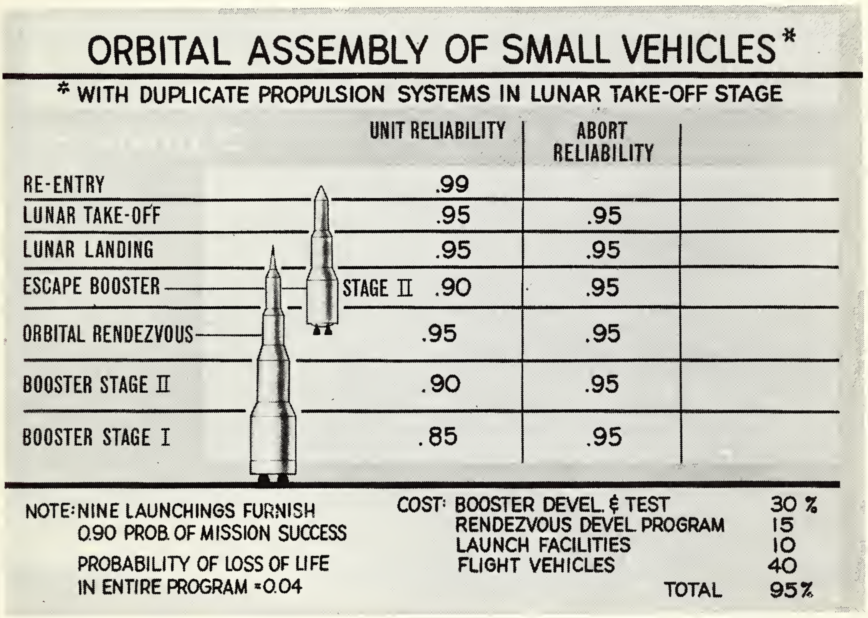


FIGURE 17. Reliability and Cost of System C.

multistage system for the same probability of mission success. An additional bonus, due to a relatively simple system for launching the manned capsule, is a reduction in the probability of loss of life from 10 per cent to 8 per cent.

Figure 17 continues this comparison by summarizing the same factors for System C, the double-rendezvous system. By using the added payload to multiply systems for the lunar take-off, the abort reliability of this part of the mission has been raised to be equivalent to that of the boost elements, whereas previously there was

no margin whatsoever for failure in this part of the system. The results worth noting in Figure 17 are that the system still is less expensive than the conventional multistage approach and that the probability of loss of life has been reduced to 4 per cent.

The conclusions from this relatively simple study that seem important to me are:

1. The state of the art and our political-economic environment make any long-range design plan or forecast nearly impossible and certainly improbable.
2. The best design philosophy for maintaining maximum technical progress in the space field may be one which accounts for design changes and can accommodate them late in the design–manufacturing–test cycle. An example of this is the rendezvous system, the elements of which are reasonably optimum for Earth-orbital missions and yet provide an economic means for more ambitious missions such as lunar landing and return.
3. New concepts not yet suggested may become predominant. For instance, the problem of "long-life" reliability may force designers to simple solutions, rather than elegant or optimum ones. Further, "stay-sane" reliability may have to await a breakthrough in the handling of the human system.
4. Finally, "get-back" reliability may force the incorporation of very redundant systems to insure high reliability in launches from remote planets.

7 CHEMICAL ROCKET PROPULSION

MARTIN SUMMERFIELD, *Professor of Aerospace Propulsion, Princeton University*

IN REPORTING on our accomplishments in chemical rocket propulsion I shall take the historical perspective and record some of the milestones—the major achievements that have marked the past decade or so. At the same time I shall consider some of the future directions that are emerging in this area.

First of all, and most spectacular, is the successful development of large-thrust liquid-propellant engines up to the F-1, the 1.5-million-pound engine for advanced SATURN and NOVA boosters. Along this route of development, we must mention the NAVAJO and TITAN engines, and the workhorse H-1 used on THOR, ATLAS, and SATURN C-1.

The next spectacular accomplishment I would cite is the improvement in reliability ratings of liquid-propellant engines. These are at a much higher level than some of us ever thought possible. Although I agree that we have some distance yet to go, what

we have accomplished so far is really remarkable. We have also developed our chemical propulsion specific-impulse level for oxygen-petroleum engines, in rough numbers, about 25 per cent higher than that of the V-2 oxygen-alcohol rocket. This is not an impressive figure in view of the possibilities of, let us say, some of our advanced propulsion concepts, but it represents a significant step forward in the chemical field.

The final development in liquid-propellant engines themselves has been the practical application of two new classes of liquid propellant. One is the high-specific-impulse hydrogen-oxygen combination for upper stages—for example, the Pratt & Whitney 15,000-pound-thrust engine for CENTAUR, the Rocketdyne 200,000-pound J-2, and the Aerojet 1.2-million-pound M-1, now under development. This hydrogen-oxygen propellant combination offers a 40 per cent increase in specific impulse over the present workhorse oxygen-petroleum liquid rockets.

The second class of newly-developed liquid propellant is the storable, instant-readiness class. The nitrogen tetroxide-hydrazine combination, used in many spacecraft concepts as well as in the second-generation TITAN, is one of the better-known examples of this class. I should remark, as a historian, that the use of oxides of nitrogen or nitric acid is not a new concept, although it has only recently achieved its full measure of success. I noted in reading some of Goddard's papers that in the early 1920s he operated his first liquid-propellant rockets with nitrogen tetroxide. However, because of various difficulties with this propellant, he turned his attention to the oxygen-based combinations for which he is best known.

In 1941 I was given the task of developing a nitric acid-gasoline rocket. The premise of our sponsor, the United States Army Air Corps, was that nitric acid would be easier to handle than liquid oxygen, permitting more convenient handling and storage at air bases. After some profound difficulties in ignition and in combustion stability, we turned from nitric acid-gasoline to nitric acid-aniline. This combination was immediately successful, permitting us to carry out our first liquid-propellant rocket flight test with 1,000-pound thrust engines on a Douglas bomber in 1942. But then nitric acid fell into disfavor because of its obvious difficulties. It was not picked up again by the Air Force until sometime around 1946 and 1947, in the form of what then was called a "major program" of develop-

ment. I would say that this program itself was essentially unsuccessful. However, we did gain a good deal of useful experience from this effort, and that experience led to the nitrogen tetroxide-hydrazine type of propellant which is of such great interest today.

The next milestone I would record is the development of lightweight, compact engine designs. Having watched the growth of our technology, I can say that the present designs represent outstanding triumphs of combustion chamber development, structural research, and component development. We should remark here something which perhaps is not always appreciated by the public, but which I am sure many of us in rocketry know—namely, that weight reduction, more than anything else, has been responsible for the tremendous increase we have attained in range, as distinguished from the mysterious concept of the so-called better propellant or better combustion that has prevailed so long in the public mind. For example, compare the single-stage THOR with the single-stage V-2. With an improvement in specific impulse of only a few per cent, the THOR's efficient, lightweight design provides an eightfold increase in range with higher ratios of payload to gross weight than the V-2.

The next item I would catalogue is the ingenious development of a whole series of essential components—for example, thrust-vector control in both liquid and solid systems, as well as start, restart, and smooth operation of liquid engines under the adverse space conditions of vacuum and zero gravity. These are typified, for example, by the AGENA and ABLE-STAR stages now in operational use.

Also included among these ingenious components are, for solid-fuel rockets, cases of exceptionally light weight and control of the thrust vector by nozzle-gas injection; for liquid-fuel rockets, throttlable engines, systems for detection of malfunction and shutdown, and reliable cryogenic flow systems. In fact the practicality of liquid rocket systems rests upon the development of such ingenious and reliable components.

Next, I would note as a true breakthrough in the chemical-propulsion field the development of castable solid propellants. This development was implemented by the mixing of potassium perchlorate and, later, of ammonium perchlorate with hardenable, resinlike liquid fuels. Many of us today take this kind of propellant for granted, but I remember a time not long ago when the best available solid propellants were those that had to be extruded or

manufactured by some cumbersome process. These processes did not lend themselves to the manufacture of large-scale rockets. The discovery of practical castable solid propellants, in my mind, was a true breakthrough; today a vast industry is based upon it.

The next item I would record is the subsequent switch to solid-fueled rocket engines as replacements for liquid systems in several important applications where liquids once were dominant. I can report that, if we go back far enough, one of the most important starts in this direction was the development of the SERGEANT missile to do essentially what the liquid CORPORAL was designed to do. Today, we have the all-solid PERSHING, POLARIS, and MINUTEMAN missiles. Ground tests have been run on prototype SATURN-class engines, and perhaps even larger solid-propellant boosters producing up to 20 million pounds of thrust may be developed.

I should remark further on the development of castable solids, starting with the discovery of this class of perchlorate propellants back in 1941. It was not until about six years later, in 1947, that some of us realized that castable solids could be applied to the long-range missile and the high-altitude sounding rocket. They were then commonly considered to be simply a desirable propellant for application to JATO rockets. Our small group at the Jet Propulsion Laboratory at Cal Tech wrote a report in which we speculated on further application of this propellant. At the urging of one of my co-authors of that report, Larry Thackwell, I shall quote briefly from our 1947 paper:

"This report considers the feasibility of the use of rubber-base propellants recently developed at this laboratory for the propulsion of rocket vehicles such as the WAC CORPORAL and V-2. The conclusion is reached that it is possible to achieve greater ranges than the corresponding vehicles propelled by such liquid propellants as nitric acid-aniline and oxygen-alcohol." The report went on to say: "It might well be asked why the application of solid propellants to sounding rockets and guided missiles was not seriously considered heretofore, and why all such vehicles being developed in the United States at the present time, 1947, are based on liquid propellants. The answers are probably twofold; first, the practicality of the V-2 and the WAC CORPORAL had already been demonstrated when the guided-missile program started on a broad scale in 1945 [that is the way we wrote it then!], and second, a solid propellant of the necessary characteristics had not yet been developed."

I may say that the impact of this report on the Ordnance Department, which sponsored it, and on several of the industrial companies was rather important and prompt.

I should include, among important advances, the general development of our industry and our profession. I have seen rocket-propulsion engineering transformed from an empirical art to an exact science. I know that there are those who will dispute the exactness of this science, but considering its state little more than a decade ago, rocketry is highly exact today. I can cite as examples the way we approach combustor design, cooling-system design, and nozzle design. Even combustion stability in both liquids and solids, a field in which there is still much research to be done, is based on a good deal of scientific knowledge. In propellant-grain design we can design a solid-propellant grain with precision and deliver a precise thrust-time curve. These are all evidences of the transformation. I can cite also the emergence of advanced educational programs in rocket propulsion at major universities—for example, the Guggenheim Centers at Cal Tech and Princeton, and similar programs at Purdue and elsewhere.

Having made this survey of what has gone by, let us speculate on a few of the possible future developments in the chemical-propulsion field. Prominent, of course, is the major program in development of large solid rockets, already partly underway for big boosters, with thorough exploration of not only the currently successful segmented designs but also on-site loading and other competitive approaches. I see increased attention to liquids and solids especially suited to upper stages and to other space applications. Mr. Ehricke has referred to some of these approaches. For example, high-performance solids as well as high-specific-impulse, high-density liquids, such as the fluorine-hydrazine combination, are still being examined for very-low-pressure, lightweight engines. I see major attention to the elimination of some of the obvious limitations of solids. For example, we still have no method for purposeful thrust modulation with solid fuels; that is, we are still unable to control thrust level at will or to stop and restart. There is a need for systems for detection of malfunction, and so on.

The next requirement that I foresee is for engines of still larger thrust than the NOVA class for major space projects, although this is so far in the future that other competitive ways to orbit large space ships, such as the rendezvous and assembly-in-orbit technique

described so convincingly by Mr. Hawkins, appear more practical for some time to come.

Finally, I see competition developing in alternative ways to place manned space ships in orbit. The all-rocket approach of MERCURY, APOLLO, DYNA-SOAR, etc., may not be the best answer in the long run. The competition may come most strongly from partly air-breathing systems, such as the high-altitude hypersonic ramjet or the various air-collecting engine cycles used with hydrogen-fueled rockets.

This concludes what I would note as significant advances in the field of space flight. I suppose there are those who would say that there have been other milestones in our tremendous development of only a few years, and there are certainly other things that we can point to as possibilities in the future. There is no doubt that all of this makes an exciting story for chemical propulsion.

8 ADVANCED PROPULSION

ROBERT W. BUSSARD, *Los Alamos Scientific Laboratory*

My topic puts me in mind of a remark of Abraham Lincoln: "You cannot build a reputation on what you are going to do." I have to deal with a subject in which there has been little real hardware development. However, another well-known remark of Lincoln is appropriate: "If you never try, you will never succeed."

Why should we try? It is well known that one of the most attractive features of nuclear energy is the fact that the fuel is virtually weightless in comparison with that for chemical energy. If this book were made of uranium 235, it would contain enough potential energy to run the city of New York for a week or so. The fact that nuclear energy is weightless is only part of the story, however, because Newton's third law still holds—even for nuclear propulsion —and we must use this energy in a way which allows us to throw mass at high velocity out of the back of a rocket vehicle.

The simplest and oldest concept for the employment of nuclear energy for propulsion simply suggests replacing the chemical fire

with a nuclear "fire" inside the rocket. The nuclear energy would be supplied by the splitting of uranium atoms inside the engine. This would heat up a propellant gas, which would then be exhausted through a nozzle. This simple concept is shown in Figure 18.

Note that this looks very much like an ordinary liquid-propellant rocket. Except for the introduction of fissionable fuel, it is a direct counterpart of the chemical rocket engine. In this case, the chamber walls must be made of some neutron-reflecting material so as to allow the nuclear "fire" to burn at the proper rate.

Unfortunately this basic gaseous-heater concept fails, because fissionable fuel costs a great deal more than conventional chemical

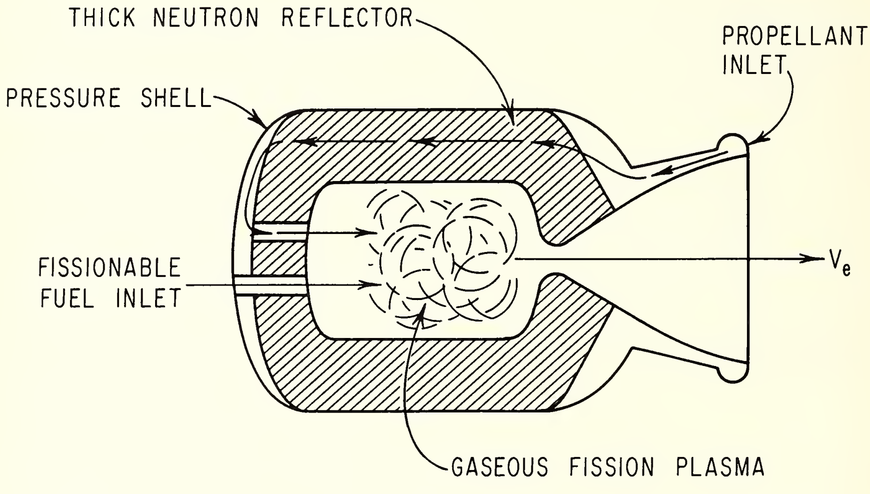


FIGURE 18. Concept of a rocket reactor using direct nuclear heating of a gas.

fuels, and we cannot afford to throw quantities of uranium or plutonium, at a cost of about $6,000 a pound, out of the back of such an engine. Because of the cost, the direct gaseous reactor has never proved exciting to anyone. It has, however, generated many proposals to solve the situation by reducing the losses of fissionable fuel. All of these methods would attempt to separate unfissioned uranium atoms from the heated propellant and to drive them back into the region of nuclear "fire" by some means—a Maxwell "demon" which would let only the right sort of atom out. The idea has not yet been proved workable in the laboratory, but there is much interesting and useful work going on.

A slightly less exotic concept for nuclear rockets, involving the use of liquid fissionable fuels, came along about 1954. Figure 19 illustrates this principle. The nuclear "fire" would not take place in the propellant gas itself but would be restricted to a liquid region at the periphery of the central combustion chamber. The propellant gas would bubble through the hot liquid fuel, be heated by ordinary convective and conductive heat transfer, and flow out of the nozzle. The fuel would be spun rapidly around the outside of the central

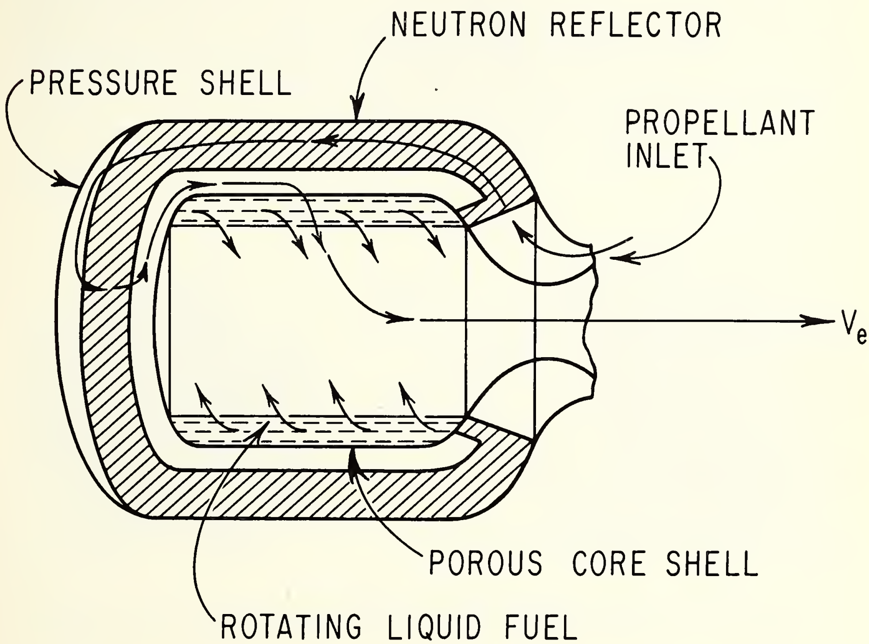


Figure 19. Concept of a nuclear rocket reactor using liquid fissionable fuel.

chamber and retained there by virtue of the difference in density between liquids and gases, just as in an ordinary centrifuge. There are many formidable hydrodynamic problems connected with this concept, which is being studied at Princeton University under the direction of Professors Luigi Crocco and Jerry Grey.

The most straightforward and practical nuclear rocket yet conceived is shown in Figue 20. Here we abandon the idea of achieving ultra-high temperatures and attempt only to heat the propellant gas by passing it through some sort of heat-exchanger matrix, obtaining

propulsive thrust in the usual manner by the exhaust of this hot gas. The only advantage of this system over conventional chemical rockets is that we no longer have to rely upon chemical sources to provide us with energy to heat the exhaust gases. This independence frees us from considerations of combustion energy when choosing a propellant for our engine. In a chemical rocket engine the combustion gases must be relatively high in molecular weight. In the nuclear case, however, we are free to choose a propellant which has a minimum molecular weight, or a maximum heat capacity per unit mass. That allows us to get the greatest possible thrust from a given mass of propellant. For this reason hydrogen is certainly one of the most attractive propellants, with about one-fifth the molecular

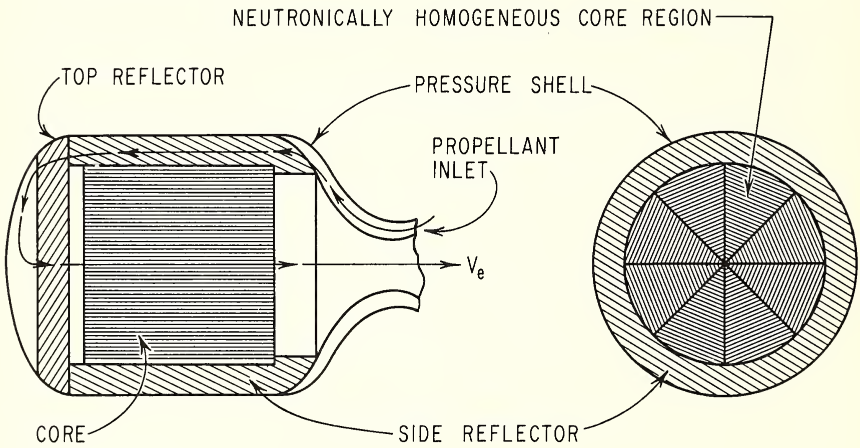


FIGURE 20. A nuclear rocket reactor with a homogeneous solid core.

weight of high-performance chemical rocket combustion products. This provides exhaust velocities (or specific impulses) about twice as high as the best chemical systems at the same gas temperature.

The question of application of nuclear energy via this route then becomes: "How hot can we make the big block of heat exchanger which is the reactor core?"

If we can heat it only to 50 degrees Fahrenheit, we surely are not doing very well. But if we could heat that block to temperatures such as those of an ordinary light-bulb filament or in the combustion chamber of a chemical rocket, we could realize the above-mentioned gains in exhaust velocity. This is the goal of the ROVER nuclear-rocket program.

Finally, there is the scheme called the ORION concept, after its project name. The ORION, or nuclear-pulse, propulsion scheme is a variation of the gaseous reactor in Figure 18. In this concept, small-yield nuclear explosives are set off at some distance below the base of a rocket vehicle. Propellant is distributed between the charge and the base of the machine, and is heated by energy transport directly from the point of explosion, instead of being contained in a can and allowed to exhaust through a nozzle. Thrust is produced simply by the reaction of this heated propellant impinging on the vehicle base. If this system could be made workable, it might yield a very high performance indeed.

Aside from the direct nuclear propulsion schemes we have considered so far, there is another area of nuclear propulsion which will be of major interest in the future. This is nuclear-electric propulsion.

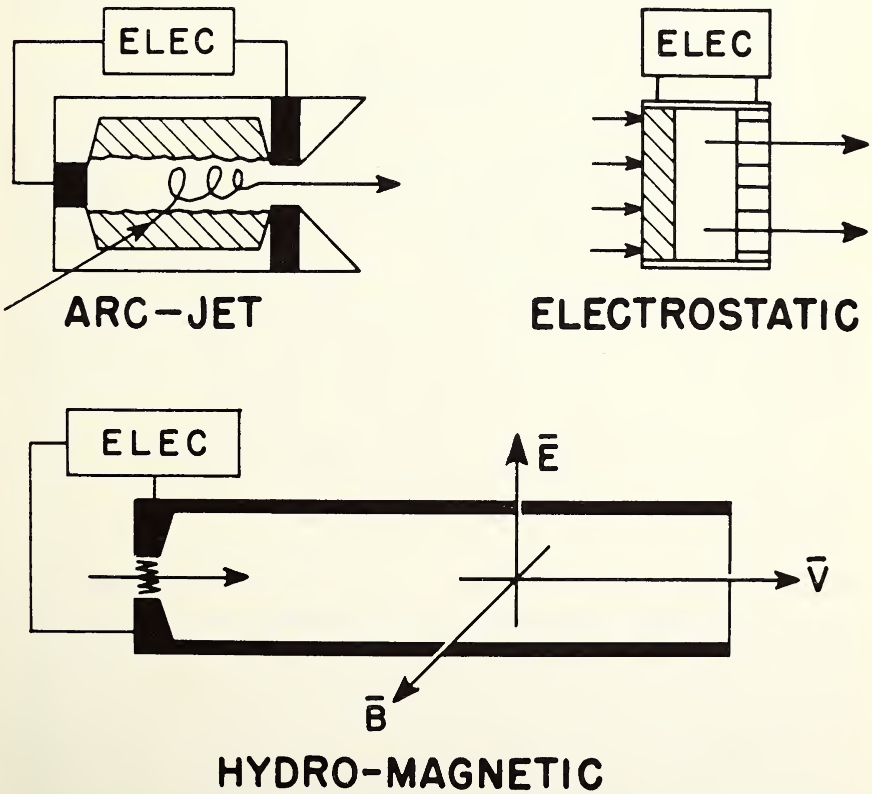


FIGURE 21. Three electrical propulsion systems.

Figue 21 shows three fundamentally different types of systems that might use electrical power for acceleration of propellant gases to high velocity. In the upper lefthand corner of Figure 21 is a device identical in principle to a chemical rocket, except that the energy is now provided by heating the propellant with an electric arc—*i.e.*, replacing the combustion fire with an electric "fire." The heated gas would then be exhausted through a nozzle in the conventional manner. This device seems limited to specific-impulse values of one to two thousand seconds.

In the upper righthand corner of Figure 21 is shown the electrostatic "ion rocket," in which a collection of positive ions is driven to high velocity by being accelerated through a negative voltage gradient, just as the electrons that produce the picture on a TV screen are accelerated through a positive voltage gradient. There are all sorts of problems of charging, ion-beam neutralization, and ion-source efficiency associated with this scheme, but these devices have been studied exhaustively in many laboratories and are now in a sufficiently advanced state for flight testing.

The electric propulsion scheme most recently accorded interest is the hydro-magnetic type of accelerator, shown at the bottom of Figure 21. A neutral plasma composed of roughly equal numbers of electrons and positive ions is accelerated by magnetic fields. Since a neutral plasma is a good electrical conductor, if we apply an electric field in one direction and a magnetic field perpendicularly to that, a force will be exerted on the plasma. The principle is exactly the same as in an ordinary electric motor, except that in this case the conductor is a gas rather than wires. The applied force will push the gas out of the "rocket" at (hopefully) a high speed.

All three of these devices require electrical power. Figure 22 shows three basic types of powerplants of interest for nuclear-electric propulsion systems. The most straightforward, shown at the top of the figure, is the conventional turbo-generator system with its heat sink, engine, generator, and heat source. If we shrink the engine and the generator and put them both inside the source, we get the second scheme, the direct cycle system shown in the lower lefthand corner. One interesting example of this system is the recently developed plasma thermocouple, heated by a reactor and connected to a heat sink. If we now shrink the heat sink into the source so that it is all one unit, we obtain the solar-powered photoelectric cell (or, simply, solar cell) already in use in many of our orbiting satellites.

Figure 23 summarizes the potential performance of these various nuclear-powered systems by plotting the attainable thrust-to-weight ratio as a function of the specific impulse (along the horizontal scale) produced by the engine. The shaded region on the left covers the performance capabilities of a direct-heater reactor. If we could heat gases to 3,500° Kelvin (about 6,300° F.), as indicated along the middle line of the shaded region, we would be able

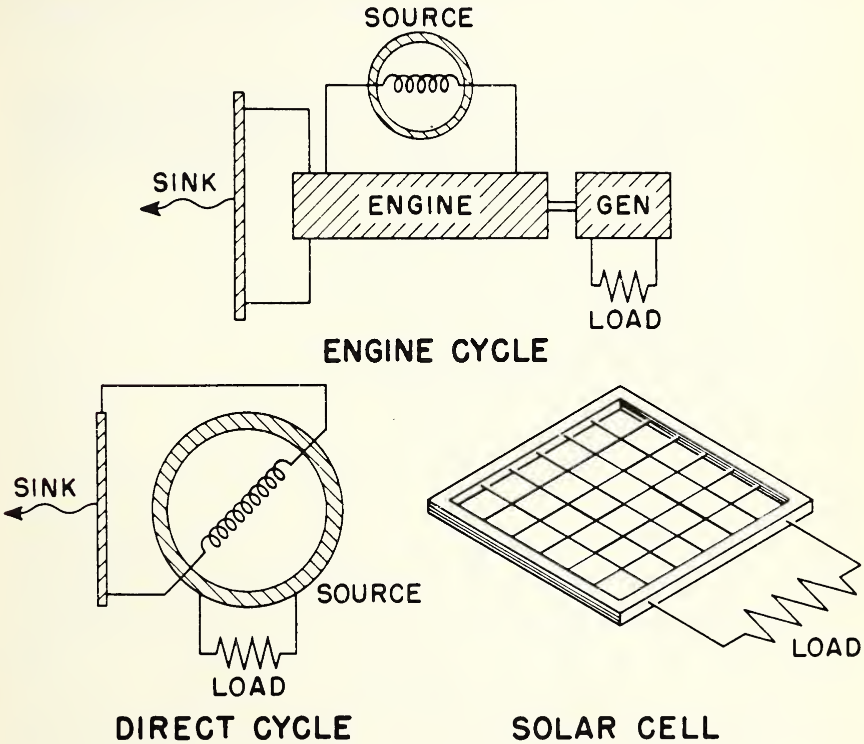


Figure 22. Three types of systems for generating electric power.

to achieve specific-impulse values up to the order of 1,300 seconds, but only at the price of decreasing the thrust-to-weight ratio to about one-tenth. If higher thrust-to-weight ratios are needed, it is necessary to accept lower specific impulses. The shapes of these curves are a direct consequence of the change in degree of hydrogen dissociation and recombination in the exhaust-nozzle flow. If we can go to still higher temperatures of around 4,500° Kelvin (about 8,000° F.), such as might be possible with the use of liquid fission-

able fuels, we could potentially achieve a specific impulse of 1,600 seconds with hydrogen. This is four times the performance of our best chemical rocket propellants

The ORION concept is shown as a bıoad and indeterminate band across the top of the picture, for the simple reason that nobody really knows how well it will work, and nobody *will* know until we are able to perform actual tests with nuclear weapons to see what sort of energy-conversion efficiencies can be obtained when these weapons are used for propulsive purposes. Although specific performance

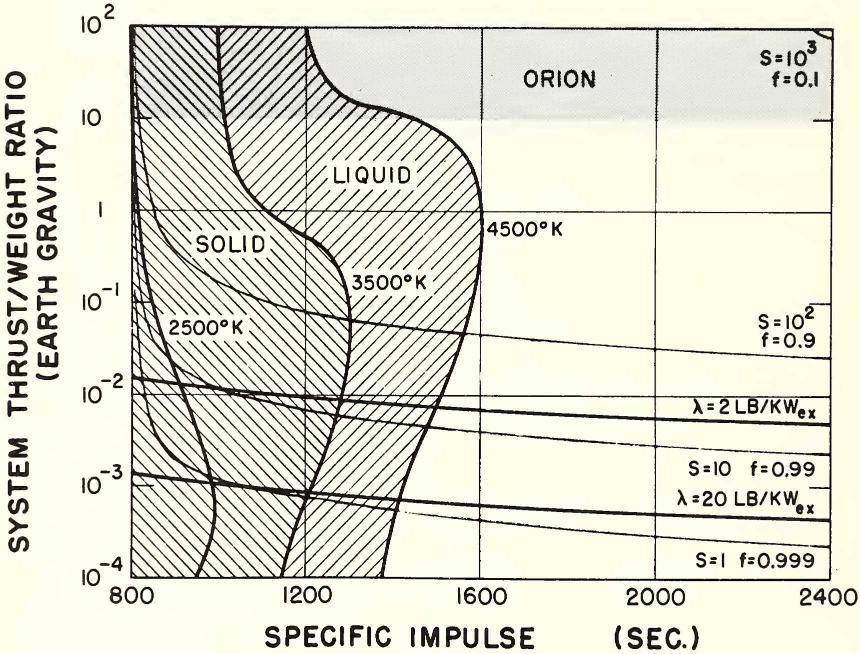


FIGURE 23. Potential performance of nuclear-powered systems.

data are hard to predict, ORION certainly possesses the potentiality for high thrust-to-weight ratios, *e.g.*, of the order of one to ten.

In Figure 23 lightweight lines are drawn to show different states of the art of the basic gaseous-reactor concept. Numerical values, designated S and *f*, are marked along each curve. The letter *f* designates the fraction of total energy generated in the solid material of the reactor, so that (1-f) is the fraction generated directly in the gas. S is a separation ratio which describes the degree of separation achieved between fissionable and propellant gas atoms.

If S equals unity, unfissioned fuel atoms are not being separated from propellant atoms at all, and still-useful, highly expensive fuel will be swept out with the propellant gas. Under these conditions, the only way to obtain high specific impulse without excessive fuel losses is somehow to discard the energy generated in the solid parts of the reactor. This requires waste heat radiators, which involve massive equipment and thus very low thrust-to-weight ratios. For this reason the curves in Figure 23 all drop rapidly with increasing specific impulse.

What we can do today with certainty in using gaseous reactors results in a rather uninteresting level of performance compared to that of some of the other systems shown in Figure 23. On the other hand, if we could generate only 10 per cent of the energy in reactor cell structure (so that $f = 0.9$) and also heat the gas to 10,000° Kelvin (about 18,000° F.), we could obtain specific impulses well over 2,000 seconds. This tremendous potential is what makes the current experimental program so interesting. However, the separation problem seems to limit practical gaseous-core specific impulses today to levels attainable from direct-heater reactors—which we know how to build—and unfortunately no good solutions are seen as yet.

The dark lines in Figure 23 represent nuclear-electric propulsion. The lowest curve shows 20 pounds of system weight per kilowatt of electrical power in the exhaust jet, which is probably a reasonable extrapolation of the state of the art for some of today's advanced developments. We observe that this performance is rather better than that of the no-separation gaseous reactor. Nuclear-electric propulsion, of course, has the potential to yield propellant specific-impulse values of many thousand seconds, and therefore it has a wide field of applications despite its inherently low thrust-to-weight ratio.

Figure 24 shows another facet of the picture. Here the lefthand scale denotes the minimum weights of practical propulsion systems of the various types. This figure includes gaseous reactors of variable weight but assumes "no separation" in the fuel flow. With this practical restriction, if we make the reactor just big enough so as not to throw away an excessive amount of fuel, the minimum weight is about 100 million pounds for specific impulses significantly greater than the direct-heater reactor capabilities.

If we examine specific-impulse values considerably higher than

those attainable with direct heaters, we might consider ORION, whose minimum size falls between 100,000 and one million pounds. Potentially, as I have mentioned, specific-impulse values for ORION may be far off the figure to the right. We simply do not know what ORION will or will not be able to do. Even if it works technically,

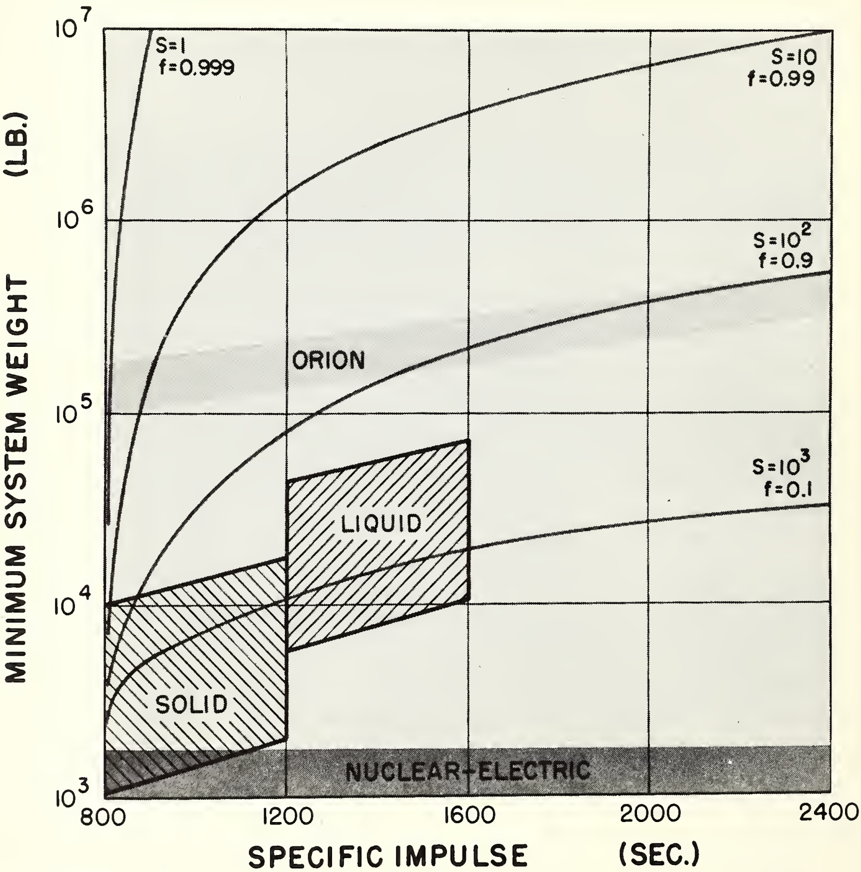


FIGURE 24. Weights of propulsion systems.

the cost in fissionable material may be so high that it is impractical. Technical characteristics can be settled only by further tests of nuclear explosives. From the standpoint of space flight and advanced propulsion, it is fortunate that the 1958-61 test ban has been lifted, because it should now be possible experimentally to prove or disprove the ORION concept.

Turning to the liquid reactor, which is probably going to be inherently heavier and larger than a comparative solid system, we see that this occupies a region in Figure 24 above and to the right of the solid-core reactor. We may expect that nuclear-electric systems might soon be built with minimum weights as low as 1,000 to 2,000 pounds, and possibly even somewhat smaller. Solid-core reactors have a minimum weight in the 500-to-5,000-pound region, limited at the low end by nuclear criticality. The general conclusions from Figures 23 and 24 are that gaseous reactors offer little practical hope at present; ORION is a big unknown; solid- and liquid-core reactors offer substantial advances over chemical rockets; and nuclear-electric systems offer comparable advances for certain applications.

It is now time to see how far we have progressed in the application of nuclear energy to space flight. Figure 25 shows one

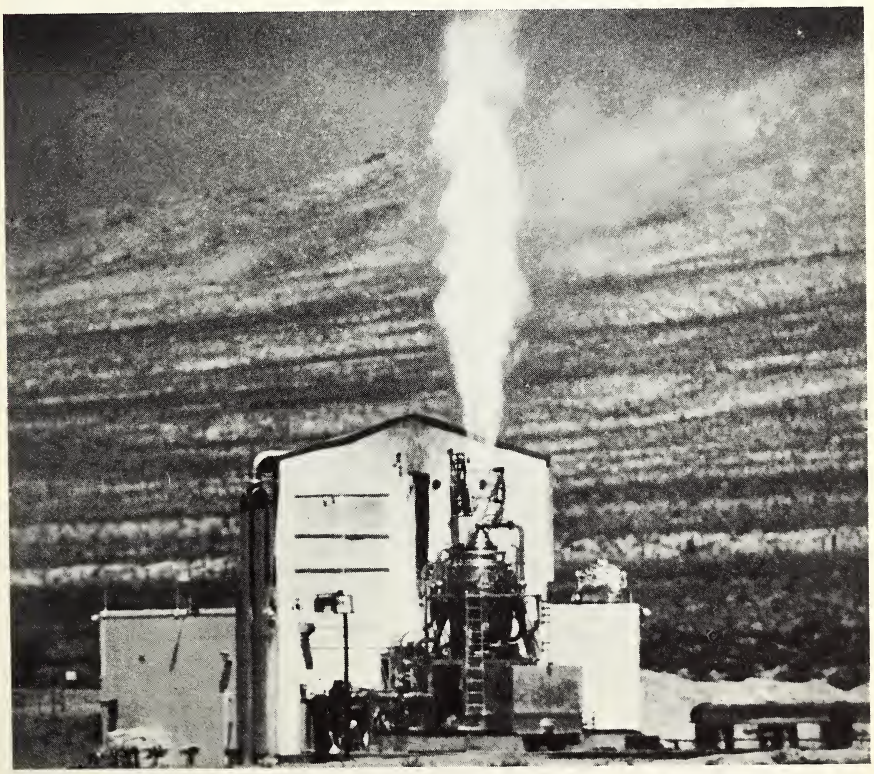


FIGURE 25. The first test of a nuclear rocket reactor.

of the important milestones. This photograph was made in July 1958 on the occasion of the testing of KIWI-A, the very first nuclear-rocket reactor tested in the history of the world. I think it is generally true, and it is perhaps pertinent to point out, that as of 1958 we were considerably ahead of our competition in the field of nuclear-rocket propulsion. Recall, if you will, that this reactor test took place only a few months after the development contract for the first F-1 engine was written. On these and later tests we based our flight-type NERVA engine program (Nuclear Engine for Rocket Vehicle Applications) and its RIFT flight-test vehicle (Reactor In Flight Test). One possible application of the NERVA engine and RIFT vehicle is shown in Figure 26—an artist's conception of a nuclear-powered spacecraft being refueled in orbit. The nuclear engine is located at the lower right, and the crewman, as shown, must stand a considerable distance away to protect himself from the shutdown radiation.

What other potential applications exist for nuclear-powered propulsion systems in space? Possibly we shall see nuclear rockets used as boosters for lifting spacecraft off the surfaces of planets; we may see high-acceleration systems used also for earth satellites and other maneuverable orbital vehicles. A system that was easily recoverable and reusable could be used to advantage as an Earth-to-orbit ferry. As Martin Summerfield suggests, the "aerospace plane" concept may turn out to be superior, having operational features similar to those of conventional airplanes, particularly the characteristic of being completely reusable.

The process of slow acceleration, using either direct nuclear heaters or nuclear-electric systems, is of interest for long flights through the solar system. The "breakeven" point between high-thrust and low-thrust devices is still a matter of considerable dispute. At present it appears to fall somewhere between the orbits of Mars and Jupiter, the exact point depending, of course, upon the state of development of the propulsion technology at any given time. For example, a direct-heater reactor yielding a specific impulse of 1,200 seconds is about competitive with a nuclear-electric system which operates at two pounds per kilowatt, for missions beyond Mars but short of Jupiter. These are, incidentally, rather optimistic performance figures for both systems.

One of the best arguments for accelerating the development of nuclear rockets is that we really want to make space a place for

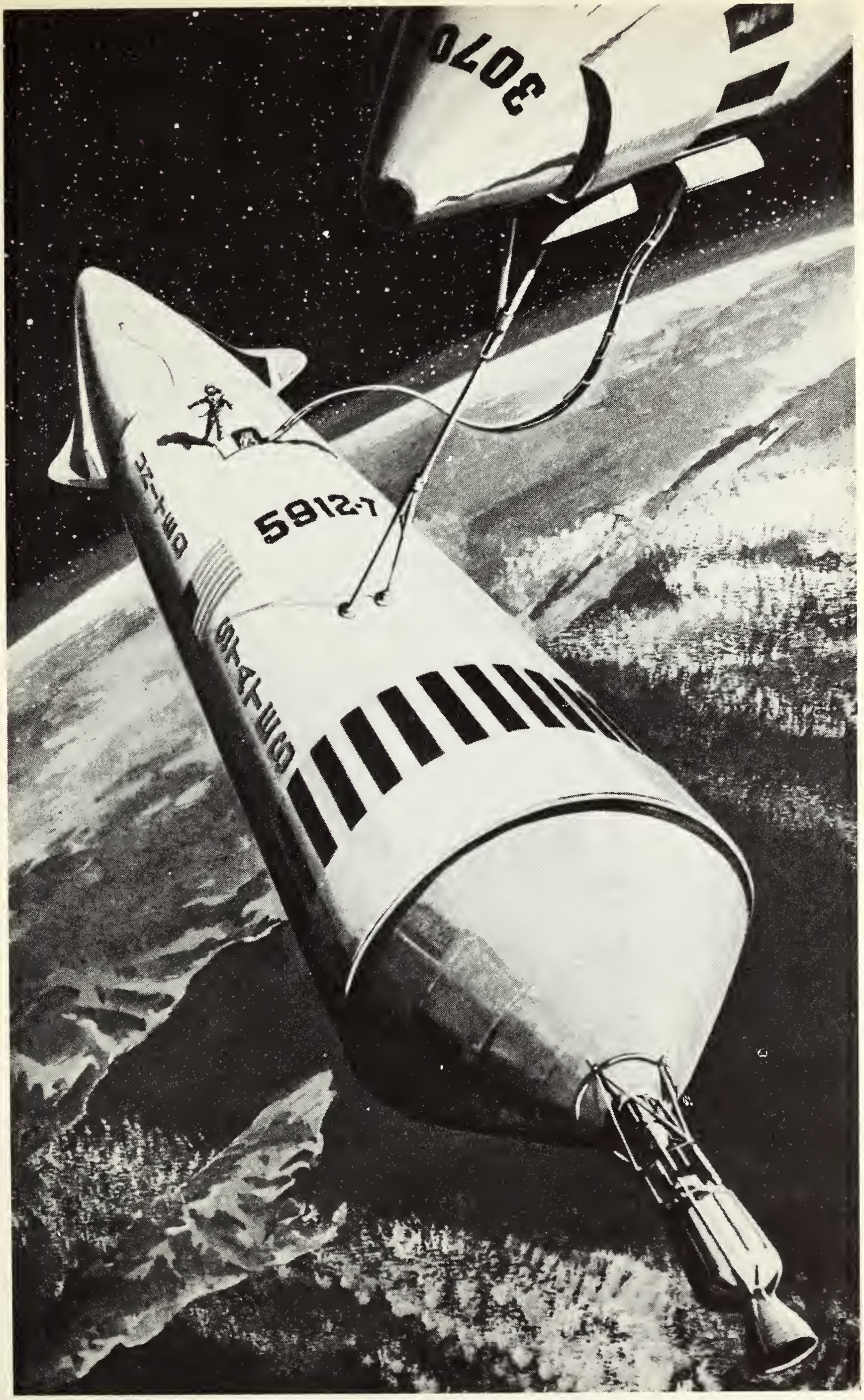


FIGURE 26. Refueling of a nuclear-powered spacecraft.

people. We cannot do this by continuing to confine our developments to the minimum-energy, last-gasp missions attainable with low rocket performance. Only by taking big steps in capability—essentially by moving to the higher performance systems—can we make space flight practical. For example, to make a turn of 120 degrees in low orbit requires a vehicle speed change of about 80,000 feet per second; a 240-degree turn calls for a change of 140,000 feet per second. These examples illustrate the major in-

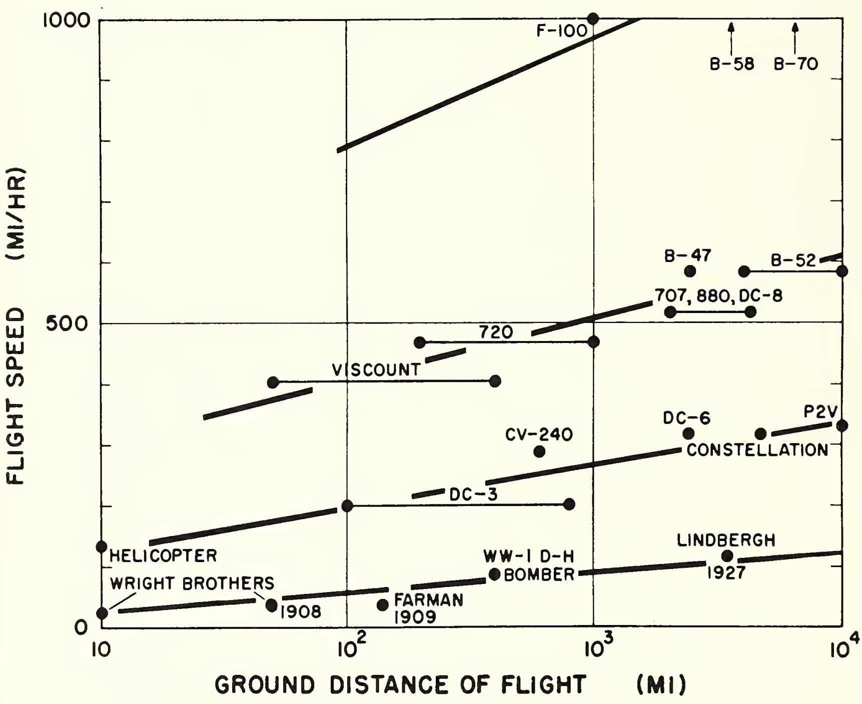


FIGURE 27. Historic jumps in flight speed.

crease in performance needed for practical short-time trips to the near and far planets, as well as for a host of soft-landing and maneuverable missions to destinations nearer the Earth. These "big jump" missions are not of much immediate interest for solely scientific purposes alone, but they are of obvious use for military purposes. Nuclear propulsion is interesting because it can give us the large increase in specific impulse needed to take the big jumps which are required to make space flight a practical venture.

This sort of progression to our goal is not entirely a dream; there are historical precedents for such jumps, as Figure 27 shows. Back in 1908 the Wright brothers flew an airplane at about 30 miles an hour for 40 to 50 miles. In 1909 Henri Farman flew a bit faster and farther; by World War I, performance had increased as indicated for the De Havilland (D-H) bomber; and in 1927 Charles Lindbergh's flight across the Atlantic capped this level of performance. The jump to the next level, which more than tripled Lindbergh's speed, took nearly 20 years. Then, within a scant 10 years, we saw two much greater jumps, the last of which reached so high a level of flight speed that it runs off our chart.

I ask you to reflect on the fact that we speak English in the United States, although the Spanish and French were the first to explore and conquer North America, because the great English queen Elizabeth I built the world's best transport fleet and the best communication system to the New World, fought to control the transport lanes—the seas—and thus won control of the new "space" of that day. It is my personal conviction that we are not exercising the same foresight and diligence needed to make the jumps to higher performance levels—to control the "seas" of space for the uses of free men. Our budget today is such that less than 1 per cent of our space-flight effort is going into nuclear-electric propulsion, and less than 3 per cent is going for direct-heater reactor propulsion systems. I leave it to you to decide whether this is enough.

9 GUIDANCE AND CONTROL

C. STARK DRAPER, *Chairman, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology*

GUIDANCE is the process of generating and applying commands to correct the motion of a guided missile toward a path that produces success in its assigned mission. Control is the process of maintaining stable vehicle motion and adjusting this motion in accordance with guidance commands.

Because these two functions may be more or less completely served by the same equipment, they are often grouped together as a single area of technology. This grouping also has an historical significance, in that long before the emergence of civilization, the first control and guidance units were men who used their eyes to sense position and motion, employed their brains to estimate needed corrections, and applied their muscle to the control of animals on the land and boats in the water. An essentially similar pattern of action is followed today by automobile drivers, aircraft pilots, and steersmen for marine vessels.

The development of transportation for our modern times has

required many technological innovations. For example, the limitations formerly imposed on visual contacts by distance, line-of-sight obstructions, night, and weather have been overcome by radio and radar. Human muscle forces, frail in comparison to the power of the machinery they must command, have been made effective over the largest vehicles of land, sea, air, and space by help from various types of actuators. Human skills and thinking abilities, supplemented by the power of those actuators and assisted by radiation-link sensors, enabled men to deal effectively with the vehicle-control and guidance situations in common use before World War II.

Between the end of that war and the present, there have been advances in control and guidance which far overshadow even those spectacular earlier accomplishments. These advances have been developed to answer both civilian and military needs.

In order to understand the course that control and guidance systems will probably take in the future, let us review some of the past developments and then examine the current problems that must be met and the means available for dealing with them.

Long ago in the history of mankind it was learned that properly selected stars provided "landmarks" in the sky which could be used to complement or replace terrestrial landmarks. To be sure, celestial navigation lacked accuracy in the measurement of longitude until the marine chronometer was perfected something over a century ago. But the stars, a good timepiece, and a knowledge of descriptive astronomy combined to help remove the ancient limitations on man's ability to guide his vehicles. Please note that this improvement in guidance was due neither to more powerful components for control nor to devices for replacing the brain's thought processes. Its key element was better information about position. This pattern of advance continues to the present day. Increased performance comes from better geometrical information on orientation and position with respect to the space in which the desired vehicle path is specified. The key area for advances in control and guidance is still the region in which the basic limitations exist—that is, in the high-accuracy sensing of geometrical information.

To those of us who were concerned with the problem in 1945, it became obvious that guidance systems depending upon radiation contacts could not continue to fulfill the operating requirements of military missions. Submarines needed to have accurate guidance during long periods of submerged sailing; bombers had to make

extended flights over unfriendly territory without cooperation from the ground; missiles had to fly fast and accurately under all weather conditions without the services of a human navigator; and ballistic missiles, following the pattern set by the V-2, had to go fast and far with automatic guidance. The then newly conceived vehicles for operating in space, beyond the earth's atmosphere and under conditions that had existed only in the imaginations of science-fiction writers, also had to have new control and guidance systems. All of these considerations were coupled with a real need for improvements over the performance given by conventional aircraft and marine instruments. These myriad requirements resulted in the stimulation and support of a program for the development of inertial guidance systems having the basic ability to operate as self-contained units without the need for radiation links to the world outside the guided vehicle.

Self-contained systems currently available are based upon internal subsystems giving the same kind of geometrical reference information that would be provided by continuously available lines of sight to fixed stars. The achievement of such references is possible because matter in the stars and the matter used for guidance-equipment components both move in accordance with Newton's laws of motion. Particles subjected to forces are accelerated in a simple way with respect to inertial space. As seen in this space, the acceleration of a given particle has a magnitude proportional to the magnitude of the force and has the direction in which the force acts. Applied to bodies outside the solar system, this principle determines the motions of stars that effectively hold their positions on the celestial sphere. Similarly, when applied to particles in well-balanced spinning wheels within guidance equipment, the same kind of action leads to gyroscopic rotors which tend to maintain the directions of their spin axes with respect to inertial space. (Inertial space is effectively identical with the space in which lines of sight to fixed stars have fixed directions.) Torque applied to a gyro rotor about any direction at right angles to its spin axis causes the spin axis to rotate with respect to inertial space about an axis perpendicular to the torque axis. The magnitude of this rotational velocity, which is called precession, grows as the torque magnitude increases, and decreases as the magnitude of the rotor angular momentum is made greater.

Proper use of instruments based on these principles makes it

possible to establish geometrical reference members which either hold initially set orientations among the stars, or rotate in this space with known angular-velocity components. In many cases the supports of the source of angular momentum, which is usually a spinning rotor, introduce disturbances that cannot effectively be overcome by the action of angular momentum without aid from auxiliary power of some kind. In cases where high performance is required, this circumstance has forced the almost universal use of angular velocity with respect to inertial space as the essential input to components designed to generate signals suitable for commanding servo-type control systems which may or may not include gyroscopic elements. In operation, many arrangements have been found to be capable of stabilizing the reference axes within small limits, while at the same time they provide drift rates very low as compared to the Earth's rotation. These achievements have effectively solved the problem of high quality orientational information for self-contained guidance systems.

Gyroscopic devices combined with servo-drives provide orientational reference coordinates of suitable quality for inertial guidance. The remaining problem is to generate velocity and position signals to indicate vehicle motion and location with respect to the framework represented by these coordinates. Because the only measurable effect directly associated with motion against inertial space is acceleration—the rate of change of velocity—indications of velocity must involve one integration, and indications of position depend on two integrations. Any integration can be concerned only with the changes from arbitrary initial circumstances that determine the starting conditions, so that all inertial system outputs are restricted to indications of velocity changes and displacements from arbitrarily chosen starting points.

For many applications, such as ballistic missile flights, lunar trips, and interplanetary voyages, indications of position and motion may be generated directly in terms of celestial coordinates. On the other hand, sea, land, aircraft, and satellite guidance indications are most conveniently given in terrestrial coordinates associated with the local direction of gravity. For the problems of extraterrestrial guidance, accelerometers based on the tendency, according to Newton's law, of an accelerated mass to "lag behind" may be used to generate signals that represent acceleration. Integration of these signals in the inertial space coordinates provided by a geometrical

reference member gives indications of velocity and position. Near the Earth, gravity introduces a complicating factor, because any device sensitive to acceleration also responds to the gravitational field. In this situation it is expedient to design equipment for tracking the direction of gravity and for using changes in the angle of this direction to indicate motion over the earth's surface. A number of good systems are now available for providing information of this kind.

Gyro units and accelerometers are capable of high performance, but they all exhibit imperfections that limit the periods during which satisfactory self-contained operation is possible. When line-of-sight contacts with known terrestrial or celestial bodies are available, these periods can be extended by properly monitoring the operation of the guidance system. Monitoring is also especially useful for vehicles operating beyond the limits of the earth's atmosphere. Future guidance systems will certainly use combinations of radiation-contact instruments and inertial devices.

All guidance systems must include electronics and computers to drive servos, to process the signals generated by gyro units and accelerometers, and to indicate the results. However, under the present "state-of-the-art" conditions, guidance-system performance does not need to be limited by the behavior of either electronics or computers. Although performance on the whole is not seriously impaired at the present time, instrumental capabilities for solving the most difficult problems of guidance are less than adequate because of gyro and accelerometer inaccuracies. Much support is now being provided for the research and development required to achieve the desired results from these components.

Newton's law of inertia is surely valid to a degree that does not limit results from inertial systems. But the mechanization of this law in terms of actual equipment is necessarily somewhat imperfect, and many differences of opinion exist as to the best way to design gyros and accelerometers. These arguments are concerned with two areas: the best way to generate angular momentum, and the best way to reduce gyro torques and acceleration-generated forces to signals suitable for servo-system commands or for use as digital- or analogue-computer inputs. Angular momentum may be generated by spinning rotors, by vibrating masses, by oscillating plates or bars, by vibrations of atomic particles, by streams of ions, by rotating rings of liquid, by gas jets, and in various other ways.

Although significant efforts have been applied to the development of all these possibilities, it is fair to state that so far all successful inertial guidance systems have been based on rotor-generated angular momentum. Rotors have generally used ball-bearings, although gas lubrication, electrostatic support, magnetic support with cryogenically produced superconducting systems, fluid lubrication, and various other schemes are being investigated. Gyro units have been built with two-degrees-of-freedom configurations as well as single-degree-of-freedom arrangements. Both schemes have been applied successfully. Only extended experience in actual operations will resolve the questions of design now being tested.

Accelerometers all depend upon balancing the specific force—the resultant effect of gravity and acceleration—acting upon a seismic element by a device which generates a signal accurately related to the balancing action. This process of balancing forces or torques is inherent in all measuring instruments; the spiral springs for torque measurement and angular deflection indications of electric meters are familiar to everyone. Because indications useful for guidance purposes must be based upon velocity and position indications rather than directly upon acceleration measurements, specific-force receivers usually incorporate some means of integration. In recent years the output signals from such instruments have very often applied as the inputs to digital computers, so that many specific-force receivers have been designed to provide signals of the digital type. Balancing effects to provide indications of specific forces acting on seismic elements have been made to depend on springs, permanent magnets and coils, eddy-current drag elements, gyroscopic rotors, vibrating wires, pneumatic balances, electrostatic condensers, and various other devices. Results with reasonable accuracy have been realized from instruments based on several of these principles. As in the case of gyro units, only experience will determine the designs that will remain competitive in the future.

The principles of guidance for vehicles of all kinds have already been demonstrated, and a technology of considerable size has grown up around the production and use of operational systems. We can expect activity in this area of technology to expand and to meet successfully the challenges of aerospace vehicles as they appear in the future.

10 LAUNCH OPERATIONS

KURT H. DEBUS, *Director, Launch Operations Directorate, National Aeronautics and Space Administration*

From the time of our earliest attempts to hurl an object toward the stars, launch methods have reflected each stage of rocket research. Launch operations have, therefore, become more and more complex and sophisticated in order to keep pace with advances in the art of rocketry. The military developments of the last 20 years have given an impetus to rocketry and thus to the evolution of a highly sophisticated launch concept.

The name given to the myriad equipment, the various buildings, and the real estate necessary to launch a space vehicle is "launch complex," This complex, serviced and operated by technicians and engineers of varied skills, performs the same basic function as the launching trough for a Fourth-of-July skyrocket: it gets the space vehicle off the ground.

However, the present launch-operations concept, with all its capabilities, is becoming a victim of the evolutionary process that

created it. The costly existing facilities, embodied in heavy, movable service towers and heavily reinforced concrete blockhouses, may soon have to give way to the more effective installations required by new space-vehicle configurations and accelerated launching rates.

An understanding of the metamorphosis of launch requirements may be gained by examining the SATURN C-1 complex. This repre-

FIGURE 28. The Saturn C-1 launch complex.

sents the latest stage in the evolution of the traditional launch concept.

The main features of the SATURN C-1 complex, shown in Figure 28, are the launch pad, the umbilical tower, the launch-service tower, the blockhouse, and the propellant facilities. The pad consists of a large concrete platform from which the space vehicle is

launched. It is based on heavily compacted soil and is equipped with a huge flame deflector. Next to the pad is the umbilical tower that maintains the link between the space vehicle and ground equipment until shortly after the first motion of lift-off. The launch service tower is used to assemble, service, and shelter the space vehicle. After its job is completed, it is moved by its own power approximately 600 feet away on rails. This is the minimum distance necessary to protect the service tower from the explosive power of the vehicle propellants should an explosion occur at launch time. The blockhouse houses the control center and is the nerve center of

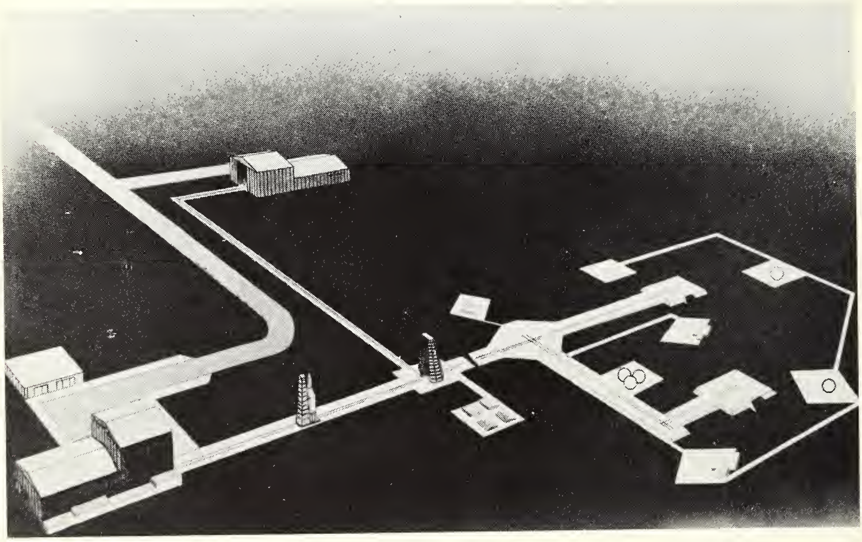


FIGURE 29. The launch complex planned for Saturn C-5.

the complex, containing the equipment required to check out and send off the space vehicle. The fueling facilities consist of propellant storage tanks and pipes connecting these tanks to the pad.

As complete and efficient as these facilities are, we recognize some inherent disadvantages. These include the long stay-time on the pad, the huge financial investment, the repeated checkouts, the required remating of the vehicle to ground equipment, and the necessary proximity of the control center to the launch site.

A major disadvantage of our present practice is the length of time a vehicle must remain on the pad. It takes approximately two

months to completely check out a SATURN C-1 vehicle and one month to rehabilitate the pad for another launching. This limits each site to four launchings a year—a very low utilization rate for an expensive complex.

The investment cost is very high. As space vehicles get larger, the launch service tower also must become larger. The height and weight of the structure impose a great load on the rail system. The tower must be capable of protecting its space vehicle against hurricanes, permitting only a minimum movement of the vehicle's upper stages. All these factors combine to make the launch service tower a very expensive item.

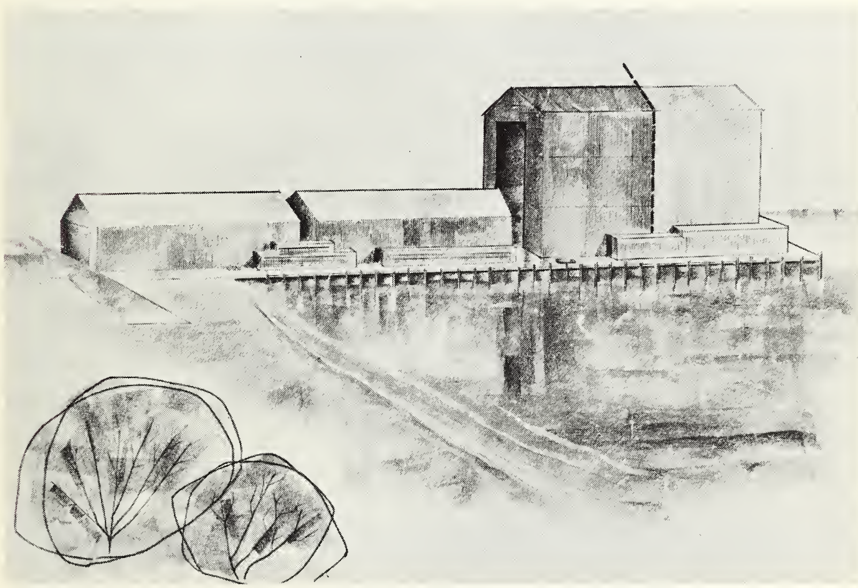


Figure 30. Saturn C-5 assembly building.

The control center also is an expensive installation. Because cables strung for any distance would entail large voltage drops, electrical interference, and difficult problems of routing, the checkout and launch equipment must be placed near the pad. This requires an expensive reinforced concrete blockhouse.

Another unavoidable expense has been the necessity of remating the vehicle to ground equipment. Umbilical cables and connections are removed in the assembly area, and the space vehicle must

again be mated to all checkout and launch equipment at the launch site. When an umbilical connection is broken, all the related data become invalid, and the checkout of involved equipment must be resumed from the beginning.

The shortcomings inherent in the present concept, as well as the increasing requirements, have made it apparent that a new approach in launch operations is needed. No radical change is possible, nor would this be desired, but attempts to solve individual problems have gradually been shaped into a collective concept which promises to resolve what we now foresee as our most vexing difficulties.

This new concept, which will be reflected first in the complex designed to handle the SATURN C-5 configuration of space vehicles, is shown in Figure 29. It will consist of a separate assembly building, a transportable launcher complete with umbilical tower, an arming tower, fueling facilities, and a minimum pad.

The entire space vehicle will be assembled in the assembly building, and then the transportable launcher will move the vehicle through the arming tower to the pad.

The assembly building, as presently conceived (see Figure 30), will be equipped to perform assembly, checkout, and launch-control operations. It will have four assembly bays, each capable of handling one vehicle; if additional assembly capacity is required, the building can readily be expanded to accommodate eight bays. Compared with the present launch service structure, this building will provide improved working conditions, freedom from the weather, and more versatile assembly operations. Although it will be hurricane-proof, its location away from the launch pad eliminates the requirement that it also be explosion-proof.

Each bay of the assembly building will contain a transportable launcher upon which the space vehicle will be erected, as shown in Figure 31. Besides transporting and launching the vehicle, the launcher will also contain computer equipment which can send or receive information over a data link to the control center. The arming tower shown in Figure 32 will be physically located at a safe distance between the assembly and pad areas. When the launcher stops at the tower, the vehicle will be fitted with retrograde rockets, fuzes, ordnance equipment, escape rockets, and other equipment considered too hazardous for the assembly area.

The minimum pad shown in Figure 33 will consist essentially of

a concrete foundation housing the flame deflector. This, combined with the transportable launcher and fueling facilities, will make up the pad area shown in Figure 29.

The rail system that makes this concept possible will be built

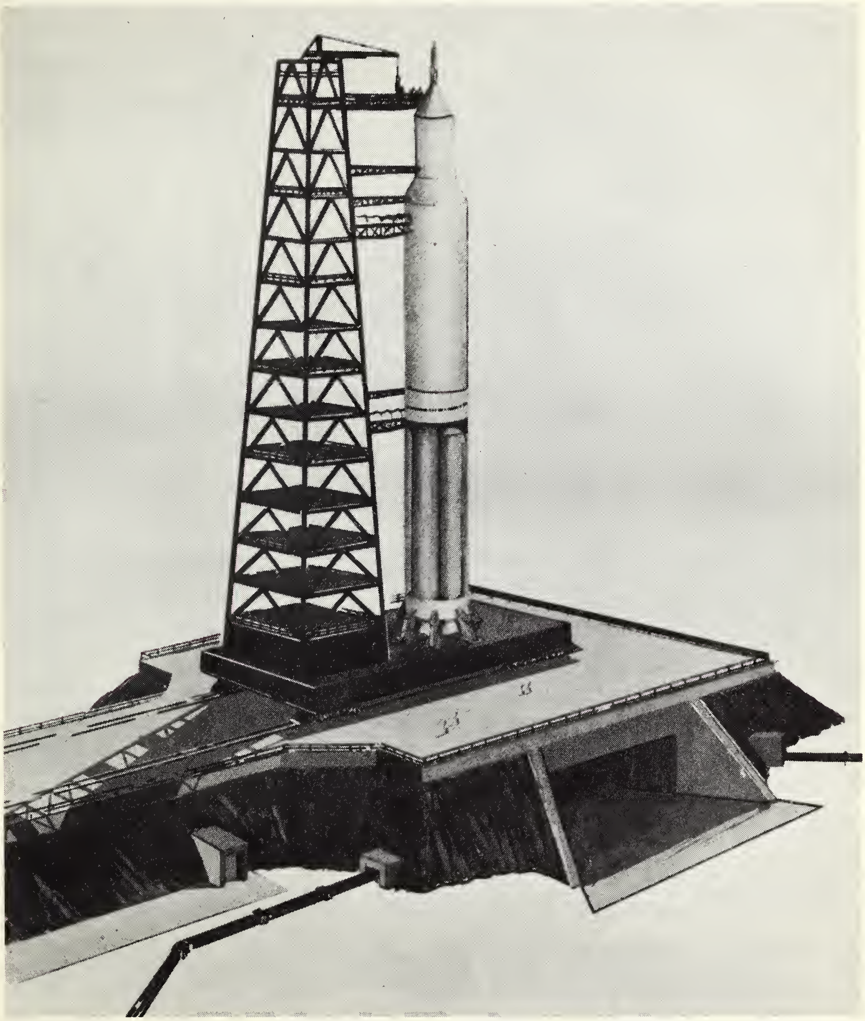


FIGURE 31. A transportable launcher for Saturn C-5.

on heavily compacted soil to withstand the combined weight of the launcher and the vehicle. It will employ hydraulic jacks to move the launcher from the assembly area to the main rail line and from the main rail line onto the side lines leading to the pad areas.

From this description, the complex may appear to require more real estate and greater investment than the SATURN C-1 complex. It does.

The cost of a C-1 complex is approximately $45 million, not including real estate. The projected cost of a SATURN C-5 launch complex is $190 million.

FIGURE 32. Arming tower to be used for adding hazardous components to the Saturn C-5.

However, this tremendous expense can be justified. First, it allows eight times as many launchings at the same site within a twelve-month period; in other words, to match this launching-rate capability would require eight of our conventional complexes, at a total cost of $360 million. This means an initial saving of $170 million.

A second factor is the even greater saving that will be realized in real estate. This concept makes it possible to launch more vehicles in the same land area. Eight complexes of the present type would require several times as much real estate as one complex incorporating the new concept. We therefore provide for a maximum use of real estate and, in doing so, add to the extensive saving from the increased rate of launchings.

In addition to these economies in facilities and real estate, this new approach eliminates many other objectionable characteristics of the present concept.

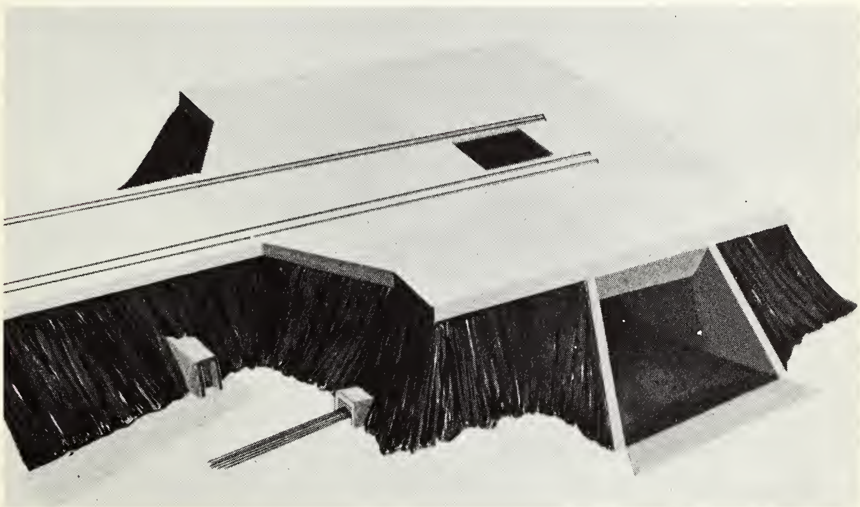


Figure 33. Launching pad.

One advantage is that umbilical connections will remain intact while the vehicle is being transported to the minimum pad. In this way we will preserve the validity of tests made in the assembly area. An interconnecting cable carrying digitized information and commands will be the only connection between the launch-control center and the space vehicle on the pad.

This suggests another important advantage—the reduction of work time. The principal reason that checkout procedures are now repeated at the launch site is the disconnection and reconnection of components. With the new system this step will no longer be

necessary. By dispensing with this activity we will also reduce launch-preparation costs.

Another value of the plan is that we eliminate the need for a blockhouse. The new concept will make it possible to check out and launch the space vehicle with one set of equipment, located in the assembly building. This will be made possible by the use of automatic and digitized equipment. Much of the present checkout and launch equipment is composed of analogue computers, whose findings are affected by voltage drops resulting from transmission over substantial distances. Since voltage fluctuations do not affect digital computers, which record by impulse, there will be no need to locate this equipment close to the launch pad.

Individual launch service structures are now used to assemble the vehicles and to protect them from hurricanes. In the new launch complex, the vehicles can be assembled before they reach the pad and can be removed from the pad area before a hurricane strikes; individual service structures will not be needed at all.

This one factor alone should result in a great saving in time and money, because the service structures are extremely heavy and impose tremendous pressure on the rail system. The present SATURN C-1 service structure is over 300 feet tall and weighs 2,900 tons. A similar structure for the SATURN C-5, if it were necessary, would be even taller, heavier, and more expensive.

One of the most rewarding aspects of this concept is the short stay-time at the launch site. Instead of tying up an expensive launch complex for three months, the vehicle will remain at a relatively inexpensive pad area for less than one week. This in turn will allow the assembly building to operate at full capacity, thus permitting a higher launch rate.

A final consideration that deserves mention is the flexibility of this complex. Separate assembly buildings for liquid- and solid-propelled space vehicles can be located on the same complex, as was shown in Figure 29. By modifying the transportable launchers and their umbilical towers to fit individual configurations, we can adapt these buildings to various manned and unmanned space vehicles. Another feature of flexibility is that it will be possible to move vehicles to the pad or back into the assembly building in a few hours, at the same time maintaining their flight readiness even under hurricane conditions.

The new concept is based on a high launch rate, and takes into

consideration the complexity of future space-vehicle configurations. It will cost less money, operate more efficiently, and be capable of launching space vehicles at a more rapid rate than is now possible. It will also be a stepping-stone toward future launch techniques which may supplant it. We already foresee that although the system will confer numerous advantages through its capability of maintaining a steady launch rate, it will not be able to sustain repeated salvo launchings. However, a single salvo of three or four launch-

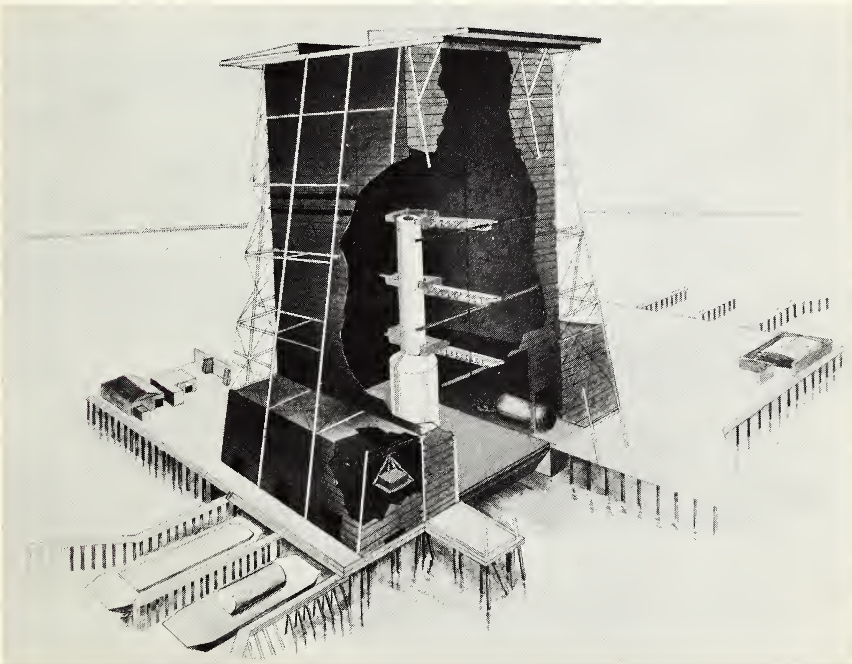


FIGURE 34. A future complex to assemble and launch space vehicles. This design is for a structure on a man-made offshore island.

ings could be accomplished in a short period. This factor, plus the tremendous size of future configurations, may result in a combination launch complex. One type, already being considered for these huge vehicles, employs a fixed structure both to assemble and to launch space vehicles. It could be built either onshore or on a man-made offshore island, as shown in Figure 34.

After the Cape Canaveral area was selected to handle these future vehicle configurations, we initiated the land acquisition

shown in Figure 35 and released general construction plans. According to these plans, the first complexes to handle vehicles larger than SATURN will be onshore installations.

Although the size and weight of these giant vehicles may dictate a temporary return to a launch-site assembly operation, second-generation complexes will probably incorporate many features of

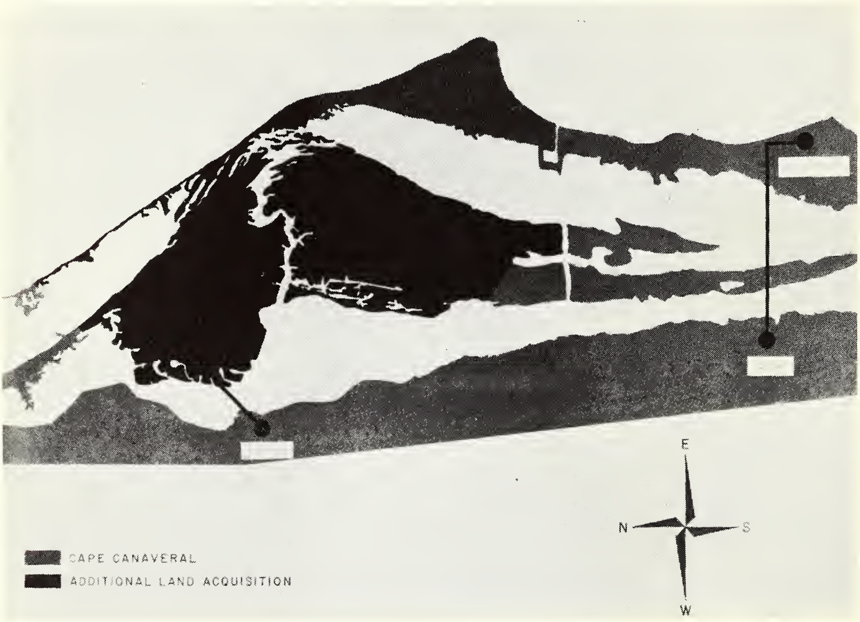


FIGURE 35. The Cape Canaveral launching area.

the new concept. If a higher launch rate becomes desirable, the new concept will become the primary means of launching space vehicles.

The American taxpayer is the stockholder in this vital business of launching space vehicles. Like all stockholders, he wants a good return on his investment. This new launch concept, besides achieving actual dollar savings, will eventually pay a handsome dividend in national prestige.

11 SPECIAL PROBLEMS

NORRIS F. DOW, *Consulting Engineer, Space Sciences Laboratory, The General Electric Company*

Among all the problems associated with space vehicles, the special ones come under just three headings: (1) radiation, (2) re-entry, and (3) rendezvous.

The aspects of these categories that I would like to emphasize are the ones for which there are not yet satisfactory solutions. Should these solutions be found, we would experience major advances in the state of the art.

The radiation hazard to manned space travel arises primarily from the possibility of encountering particle streams from one or more solar flares while the vehicle is outside the protection of the earth's magnetic field. Although the numbers and energies of protons encountered during solar flares varies enormously, the accumulated dose that an unprotected man might receive becomes more and more serious the longer he stays in space. There is no question but that for extended missions some kind of shielding of man must be provided.

The weight of shielding material needed has been calculated on various bases by a number of people, with a very wide range of answers. But all agree, first, that the weight is somewhere between "large" and "prohibitive," and, second, that not much can be done to reduce the weight if the shielding has to be thick. There is a possibility, however, of cutting weight by using an *active* type of shielding. By "active" I mean the use of high-intensity magnetic fields or high-voltage electrostatic fields to divert charged particles. How successful this approach may be depends primarily on two

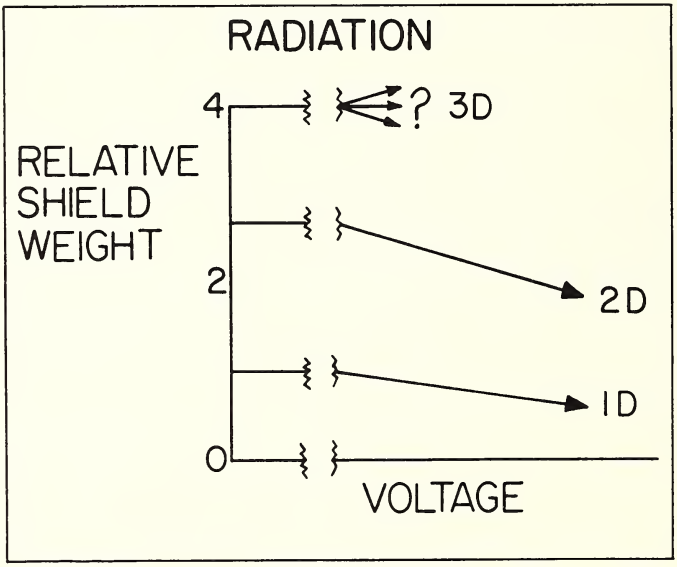


FIGURE 36. Relative weight requirements for active shielding against natural radiation in space.

unknowns, which are, I believe, the crux of the radiation problem. These unknowns are: (1) Just how directional are the incoming particles? (2) How high a voltage drop can be built up in space?

To illustrate this problem, I have plotted in Figure 36 the relative weight of shielding required against the voltage drop at which breakdown and arcing between deflecting electrodes occurs for three possible directionalities of the particles. When the particles all come in from one direction, like rain (1D in the figure), only an umbrella-like shield is needed. When they come in from

all sides but not from above or below, like traffic at a many-way intersection (2D), the sides must be shielded but not the top and bottom. Only when the particles come from every direction (3D) will the vehicle need to be completely enveloped in shielding.

Now electrostatic shielding probably could reduce the shield weight for 1D or 2D particles if voltages above 20,000 volts per centimeter (beyond the break in the lines of the figure) could be maintained in space, and the higher the voltage, the lighter the shielding needed. For 3D particles the picture is less clear; the voltage might have to be very high to be effective.

The radiation problem, then, poses crucial questions about particle directionality and allowable voltage, and we must have better answers to these questions before we can say how hopeful we can be about shielding.

Re-entry is often considered a solved problem. But to say this, particularly when one speaks of manned re-entry, is like saying that when the Wright brothers got off the ground, the problem of flight was solved. Present re-entry bodies are subjected to accelerations so violent that only the most highly trained astronauts in special couches can live through them. And one of the ways we "solve" the problem of re-entry heating is to let the vehicle body burn up, counting on still having some unburned material left when we are through.

There are, of course, many developments now going on to improve the situation. There is one major development, still only a potential one, which I should like to emphasize here for two reasons: first, because it is one of the few that acts to reduce the high accelerations, and second, because to my knowledge this aspect of re-entry has not been emphasized before.

This development will make use of the paraglider re-entry aid invented by Rogallo to broaden the "corridor" of possible re-entries. The width of the re-entry corridor is determined by how far above or below the nominal flight path the vehicle may go and still re-enter successfully. The corridor is bounded on the bottom by trajectories that plunge into the atmosphere too steeply, building up excessively high accelerations; it is bounded on the top by paths that do not penetrate far enough into the atmosphere to slow the vehicle down, so that it misses altogether and goes on out into space. A suitable paraglider would operate to extend this upper boundary. The bigger the paraglider (*i.e.*, the higher the ratio of surface area to

weight of the vehicle), the wider the entry corridor. The lower boundary remains the same as for a vehicle not equipped with the glider, because the paraglider is not opened if the trajectory is too close to the atmosphere.

The crux of this problem is the paraglider material. Even though the re-entry heating rate is comparatively low because of the low wing loading, the paraglider still needs to be capable of withstanding high temperatures for long periods. On the other hand, it must be made of a light, flexible material resembling cloth. The required development item, therefore, is a refractory material in the form of a fabric—by no means an impossibility.

Finally, the rendezvous problem, because its solution will effectively increase the launch-weight capability of boosters, is the third special problem to be emphasized. There is nothing novel about the rendezvous concept: science-fiction stories have long described the construction of "space stations" launched in pieces and assembled in space. Novel to many people, though, I have found, is a concept proposed by Houbolt in a paper he presented in Paris in 1961: landing on a remote celestial body via use of the rendezvous method near that body. This is such a powerful technique for reducing launch weight, as I discovered without knowing of Houbolt's work, that I think it deserves emphasis here.

Let us consider, for example, the landing of a manned vehicle on the Moon. As against the usual concept of landing the entire spaceship and having it take off again, suppose that the main vehicle orbits the moon and the landing is made by a small ferry, which later takes off to rendezvous with the main vehicle in its orbit. The weight saved by this type of rendezvous is substantial. For example, if the ferry is one-third the spacecraft weight, the total weight that must be boosted from the Earth to escape velocity is cut in half. I might add that this is my own extremely conservative estimate, and Houbolt shows that the gain can be as much as twice as great as this.

The special problem here encompasses all facets of the difficulties of *gently* bringing together two vehicles in space. The propulsion, guidance, and control aspects have received a great deal of attention; the actual docking maneuver and the important design details of shock absorbers and latches have not yet been investigated quite so thoroughly. I suspect that the solution of the rendezvous problem lies mostly in the demonstration that this

docking maneuver can be accomplished. Once that has been demonstrated, dramatic gains will become feasible.

Solutions to the three major "special problems" I have discussed are as important as solutions to propulsion or guidance and control problems in advancing the state of the art of space vehicles. The way toward their solution seems to be clear in all three cases. For the radiation problem we need measurements of the directionality of solar-flare particles and of our capability of maintaining high voltages in space. For the re-entry paraglider we need a refractory fabric. For rendezvous we need a flight demonstration. The conclusion, then, is that since the way is so clear, these advances should not be long in coming.

GENERAL DISCUSSION

QUESTION: What should be the relative concentration on nuclear Earth-orbit vehicles as compared to chemical earth-orbit vehicles?

HAWKINS: In the development of nuclear-propulsion systems we have moved comparatively slowly, in the hope that we could sort out the good ideas from the bad by means of studies. This is somewhat contrary to the approach suggested by one experienced engineer, who has had a lot to do with space experiments: "Go fast, and make your mistakes as soon as possible." I would like to see additional concentration in the nuclear area, even to the possible detriment of some of the other propulsion systems, in order to sort out the best ideas by test and experiment and to get a more straightforward development program going.

QUESTION: How would you recommend streamlining the present NASA space program to maintain and

improve our national position in space, while at the same time substantially increasing the efforts on nuclear rocket development?

Bussard: In general, we can consider two possibilities:

(1) *If the total money is fixed*, there is no alternative but to reassess what we are doing. We are going to have to cut into existing programs and not do some of the things people have talked about doing. This is a very unpopular course of action, because everybody is interested in his own program. Therefore it seems completely inappropriate to try to identify the specific programs that might well be cut back. I would merely suggest that a reduction be made in the funding of research on unmanned space vehicles; that is, the purely scientific research aspect of space exploration by unmanned vehicles. Money saved by cutting back in some areas of this work could be used to increase support for the development of nuclear-propulsion systems for *manned* space flights.

(2) The second alternative I would submit is that *the total money not be kept fixed.* We should not dismiss this alternative categorically on the basis that the tax budget is too high already. I find it difficult to believe that we of the United States can honestly say that, because of a high tax budget, we are not going to spend another dollar or another billion dollars to build the kind of manned space systems that may be found essential to our military capabilities. Space propulsion research and space exploration grew up under the ground rule, "Space for Peace," but space might turn out to be just another arena for man's conflict. The nation that decides it is not going to take part in that conflict will some day awake to find itself in a less advantageous position. From this point of view, we can certainly justify an increase in expenditures to develop nuclear propulsion for manned vehicles for space exploration and utilization.

Ehricke: I agree with Dr. Bussard. My answer would be similar to his. However, I would like to stress that in reality the total sum of money has to stay constant. An agonizing reappraisal must therefore be made of each area of work. The space-flight program is not obligated to make everybody happy in terms of money distribution. I believe that we will have to take a very strong and stern stand to determine the most promising individual things in each area, whether in propulsion or vehicle development.

We have to make a strong distinction between what is marginal and what represents a big step. I am sure that in the next hundred years we could do better and better in the chemical field, develop more and more vehicles, and gradually reduce the payload differences among them, so that we would have a continuous spectrum, with many vehicles of tremendous refinement. This slow, steady progress, however, has to be weighed against a policy of seeking major breakthroughs such as nuclear propulsion. Some of the steady progress will have to be given up in order to use the money to further the nuclear development program. This should be more than enough to triple our present program. I would say also that we should definitely add—and this will probably require some additional money—a nuclear test program as soon as possible to evaluate the ORION system.

QUESTION: Please comment on interplanetary duct propulsion, which would scoop chemical propellant from the chemosphere, ionosphere, etc. The specific impulse should be infinite.

SUMMERFIELD: As you know, in the very high atmosphere there are compounds and species which are in non-equilibrium states because of photochemical reaction; for example, ozone, monatomic oxygen, atoms in excited electronic states, monatomic nitrogen, etc. It is possible to provoke recombination of these unstable energetic species with some type of "ramjet." Calculations have been made as to the possibility of developing useful thrust by scooping in this kind of atmosphere. We have found that, in order to counteract drag, the vehicle must be only slightly below orbital velocity in order to stay up. The utilization of this type of propulsion at this time, therefore, seems doubtful. In the question the word "interplanetary" was used. It seems to me that there is not enough material in interplanetary space to effect important changes of motion.

EHRICKE: The only suitable proposal of this type that I know of at the present time is not for interplanetary but rather for interstellar trips, at relativistic flight velocities. At such velocities, of course, space distinctly becomes no longer a vacuum but takes on the nature of a rather dense medium. Whether or not these velocities can ever be achieved cannot be decided on the basis of present

technology. I do not think that the velocities we presently envision in interplanetary flight, even with the fast transfers, are large enough to get any significant benefit from scooping up material between the planets.

Question: What role do you see for an air-breathing booster stage for space-vehicle systems?

Summerfield: I have a feeling that space developments which depend solely on launching via the chemical rocket represent a big gamble and are not necessarily the best long-run solution. I also have a feeling that we have to examine seriously the possibilities of utilizing atmospheric lift. I would therefore sympathize with the view expressed, as implied by the question, that something should be done to examine the possibilities of air-breathing systems for high velocities.

Question: Will launches from the Moon be as complicated as those from Cape Canaveral?

Debus: I do not know, but I hope not. Highly automatic systems have been developed, but security classification does not permit us to discuss them. These are not usually seen at the Cape, where vehicles are mostly in the research and development phases. I believe that certain of these techniques can be developed so that the checkout can be done at the Cape prior to initial launching, thereby simplifying the lunar-launch procedures. There are some definite advantages in lunar launchings; one is that there should be no flight-safety problem.

Ehricke: I would like to use this opportunity to put in a plug for nuclear propulsion, although some people may not agree with me. I believe a restart or relaunch from the lunar surface with nuclear propulsion would be easier and less complicated than with chemical systems.

Bussard: There are two aspects to the use of nuclear rockets. Many of the failures in chemical rocket systems have come about because of troubles in the first fraction of a second, during ignition. In a nuclear rocket there is a long time-lag before starting, and for this

reason one does not anticipate as many difficulties or failures in the start of a nuclear system. Thus the nuclear device should have an inherently high reliability for restart application. On the other hand, it presents special hazards. On taking off from the Earth's surface, there would be air-scattered radiation which could harm somebody, and in a take-off from the Moon, there would be ground-scattered radiation. There is also the problem of getting in and out of the vehicle landing area, or to and from a nuclear-powered vehicle that is grounded in an airless area.

However, these problems are not insoluble. A shielded nuclear rocket reactor could be made, if it were provided with enough power. It looks very much as if this desirable goal is attainable without extreme difficulty or cost in development. Shielding for manned operations is a problem, but I think we know how to solve it.

EHRICKE: This is an example of the need for composite thinking. We need shielding in space anyway, in order to provide protection against solar flares. If we could utilize nuclear propulsion to travel to the lunar surface, separate the heavily shielded capsule and put it down chemically and gently away from the nuclear engine, we make full use of nuclear propulsion. At the same time, the shielding would also serve for protection of the crew against natural radiation. Shielding for this protection is needed even in a chemically propelled vehicle.

> QUESTION: What is the largest chemical booster that could be accommodated in the projected on-shore launch facility?

DEBUS: It will accommodate rockets of either ten million or 20 million pounds of thrust.

> QUESTION: Has your new facility considered the ground launch of nuclear vehicles?

DEBUS: Based on what we know at this time, there should be no adjustment problem. The problem that would be created by impact of the upper stage before it became active would be insignificant. The safe distances are dictated by two basic factors, both of which are under study. One is the noise, and the second is an explosion of an equivalent amount of liquid hydrogen and fuel. The problem

of launching large chemical rockets with a nuclear upper stage has been studied in detail by the RIFT contractor, and there appears to be no fundamental obstacle to this type of launch.

> Question: What is the reason for two pads in the proposed complex?

Debus: This, as I understand it, is a salvo problem. The present planned launch rate is 32 per year. Two pads and one spare are provided. Configurations of the SATURN C-5 class on two pads could be fired simultaneously. I believe that the only limiting factor here would be the instrumentation needed, since different instruments would be needed for tracking different frequencies. As far as I know, there is no need for an absolutely simultaneous launch, but it is possible. If the launchings are separated by one or two hours, there should be no problem in receiving information from both flights. Within a span of a week we could launch four vehicles from one complex. If a salvo of eight should be required, we would need two of these pad complexes. As it stands now, I do not believe this will be necessary.

> Question: Does the specific-impulse increase achieved with hydrogen-oxygen offset the increased structure factors due to reduced density? If so, why restrict hydrogen and oxygen propulsion systems to upper stages?

Summerfield: I would say it makes sense to use it for the first stage. However, we must remember the development environment in which we find ourselves: we have no operational hydrogen-oxygen rocket. We have, first, the development problem, and secondly, the supply and ballistic problem of handling large vehicles, so it makes sense to start small and grow big. Furthermore, it also makes sense to make the higher-energy stage substitution in the upper rather than in the lower stage, because high performance in the upper stage automatically induces an economy in the lower ones as well. Thus it makes a lot of sense, at our present state of development, to start with the upper stage. Whether it would be feasible, desirable, and economical to move to a lower stage will depend upon finances, the size of the program, and so forth.

EHRICKE: The idea has merit, but if we already have a vehicle that does the job, why develop another to do the job just a little better?

SUMMERFIELD: May I join you in that sentiment? It is obvious that we can make improvements in existing standard chemical configurations with the expenditure of more money. It is also obvious that we can accelerate our crash programs, the ones we think are important and in which we are competing with the Russians, by the expenditure of large space budgets, leaving only a small residue for the new ideas. I would like to discuss this sentiment with respect to the nuclear program and with respect, by the way, to other new ideas that may be on the horizon. There is danger that in the effort to save perhaps a year or so in our space program, we may try to push through a number of important crash programs solely with the information and with the developments at hand. We could take all available resources and pool them in the crash program, but this would automatically starve out new ideas. There may come a day when we want and need some better ideas but do not have them in time.

EHRICKE: Above all, we must realize that if we want to accomplish something in 15 years, we have to start doing something about it now. Usually we put it aside and wait until it is almost too late. We have to implement advanced ideas with whatever funds are available, and we often, therefore, get them funded by one of the crash programs.

BUSSARD: The specific-impulse, mass-ratio argument has, of course, been debated for years in nuclear rocket propulsion. There is no general answer as to the "best" propellant, because the actual tradeoff is dependent upon the mission requirement. However, we can get some feeling for low *vs.* high specific impulse from results of a study made at Los Alamos* on sizes and weights of a variety of chemical and nuclear systems to soft-land 55,000 pounds on the Moon.

With four chemical stages having one liquid oxygen-hydrocarbon stage and three oxygen-hydrogen stages on top, the gross

* "Nuclear Powered Lunar Rockets," LAMS-2515, by Ralph S. Cooper, Los Alamos Scientific Laboratory, April 17, 1961.

weight is close to ten million pounds, and the volume about 200,000 cubic feet. Every time we replace a chemical stage with a nuclear stage, the gross weight is cut by the order of a factor of two to three, and the volume of the complete system also is reduced considerably. Replacing the three upper stages with two nuclear stages, but retaining an oxygen-hydrocarbon booster, leads to the minimum vehicle system, weighing about 1.6 million pounds and having a volume of about 80,000 cubic feet. The booster stage in this system provides a velocity increment of some 13,000 feet per second. Now, as we go to an all-nuclear system, the volume becomes larger although the gross weight is smaller, so for this kind of lunar mission the high specific impulse pays off all the way down to the oxygen-hydrocarbon booster of the just-mentioned case.

> Question: Do you anticipate a need for radio-augmented or stellar-augmented inertial guidance systems, or do you believe that improvement of all the inertial components will render the older systems unnecessary?

Draper: To answer this question, I would like to repeat a few words of my original statement:

"Gyro units and accelerometers are capable of high performance, but they all exhibit some imperfections and limit the time periods during which satisfactory self-contained operation is possible. When line-of-sight contacts with known terrestrial or celestial bodies are available, these time periods can be extended by properly monitoring the operation of the guidance system. Monitoring is also especially useful for vehicles operating beyond the limits of the earth's atmosphere. Future guidance systems will certainly use combinations of radiation-contact instruments and inertial devices."

So I believe that, especially for operations in outer space, primary dependence will be on line-of-sight, and the inertial devices will be used for the purposes of refining the accuracy of continuous operation without having to tie up so much equipment in looking at celestial bodies. My answer, therefore, is yes, a line-of-sight contact device *will* be used, the exact combination depending on the mission.

III. The Global Effects

EDITORS' INTRODUCTION

One of the dominant considerations in our national space effort is its effects on the people of the United States and the world. Although these effects cannot be predicted completely or in detail, some results may be anticipated. The following section concentrates on the non-technical influences of space exploration.

General Doolittle observes that we are committed to more than merely a technological space race with the Soviets. The space program may be the primary arena of competition, but it serves only as a pivotal point. The conflict goes beyond the technical area to involve our philosophy of government, our ideology, our economy, and our military strategy.

In viewing the direct military effects of space flight, Mr. Gardner notes the compatible integration of technical military needs with civilian needs. Advances in both areas have generally proved of mutual benefit. However, the civilian and military groups must

seek even more support in funds, in men, and in material if this country is to achieve its goals in the space race.

One of the most crucial areas for concern is the international effect of the United States space program. Dr. Morgenstern highlights the geopolitical effects on the world of the United States-U.S.S.R. competition. He points out that we are committed as a nation to the space race, and that our country has no real choice in this matter. We must continue and we must succeed. Dr. Morgenstern seriously questions that any satisfactory working arrangement between the two nations can be made and kept, since each considers it vital to emerge the "victor" in any agreement made concerning space.

The economic impact of the space program includes its effects on private business, on new-product development, and on the attitude of the United States citizenry toward funding space flight projects. Mr. Mitchell forecasts industrial and economic changes that will be brought about by innovations in the aerospace industry. He enumerates the problems of financing space-flight research and, finally, notes the interrelationships between space economics and our business economy.

The possibilities for improved international cooperation through new modes of communication are reviewed by Federal Communications Commissioner Craven. Mr. Craven warns that more than technical advancements are needed. Technical improvements bring new communications problems which must be solved on a social and economic level. It is not improvement of the equipment but improvement in the use of the equipment that will determine the level of relationships among peoples.

The final topic in this section goes beyond global boundaries to survey the relationship of our investigations to the Universe. Dr. Morrison considers the possibilities of encountering intelligent life elsewhere in space. He believes there is a high probability that we on the planet Earth will hear from intelligent races on planets outside our own solar system. Professor Morrison points out that our imminent planetary probe missions, particularly to Mars, will answer important questions concerning the possibility of the existence of alien intelligence in other solar systems.

PROLOGUE

JAMES H. DOOLITTLE, *Chairman of the Board,*
Space Technology Laboratories, Inc.

TODAY we are in an intense ideological, scientific, technological, and economic conflict with the Soviet Union. One important phase of the conflict is the so-called space race. It is high time that the broad consequences of this space effort be considered seriously by the American people.

In these times of international tension a paramount consideration is the military effect of space exploration. We are fortunate in having Trevor Gardner, chairman and president of the Hycon Manufacturing Company, to lead the discussion in this area.

The geopolitical implications of space activity are potentially more far-reaching than we can fully appreciate at this dawn of the space age. We can already see that the conventional concepts of geographical sovereignty will be subjected to severe stresses as a result of what space technology has accomplished. It is our privilege to have on this panel Dr. Oskar Morgenstern, whose participation in Princeton University's Econometric Research Program is contributing significantly to a definition of the issues involved.

We have already witnessed evidences of the sweeping industrial economic effects engendered by the advent and development of the aerospace industry. Some of the results have been painful, as the requisite skills and talents changed radically in a short period. A review of this area is presented by Mr. Donald G. Mitchell, Vice Chairman of the Board of the General Telephone and Electronic Corporation.

The hope of international cooperation is a major consideration amid the concern generated by the many aspects of our space technology advance. We are all painfully aware that at present this is far from being realized. The interests of those seeking knowledge through space exploration for the betterment of man can be indulged realistically only so far as the urgent requirements of the free world's security will permit. Granting this requirement, good communications are still important. Communications may help to dispel fear and pave the way for cooperation. Poor communications invite suspicion on the part of one group concerning the motivation of another. Mr. Tunis A. M. Craven, our panelist in the field of international cooperation, is well grounded in that firm requisite of cooperation—good communications.

The beginning adventure into space inevitably suggests that we may be close to extraterrestrial contact. Physical contact with our planetary neighbors will occur in the very near future. Travel beyond our own solar system poses serious problems, for which solutions are not presently apparent. But signaling as a means of contact is already demonstrably practical. Our guide on a tour of the intriguing possibilities of extraterrestrial contact is Dr. Philip Morrison, Professor of Physics at Cornell University.

12 MILITARY EFFECTS

TREVOR GARDNER, *Chairman of the Board and President, Hycon Manufacturing Company*

In 1958 a Soviet "scientific" experiment, the SPUTNIK, shocked and bewildered the world with the first impact of the space age. The Cold-War cost of the U.S.S.R. SPUTNIK experiments was immediate and has continued to adversely affect our national security. The loss of prestige by the United States cannot be accurately assessed; its seriousness cannot be discounted. It will continue until we lead in the space race. The Soviet accomplishments in space no longer affect our future national security in only an indirect manner. Soviet space power at this time is a direct military menace.

The military significance of the Soviet big-booster lead, the Gagarin and Titov flights, and the recent Soviet nuclear explosive and ICBM test series cannot be ignored or wished away. When we couple the meaning of the Soviet resumption of nuclear testing with the power in space they have demonstrated so clearly, the Soviet space threat becomes a cause for grave national concern.

We must re-examine our national space program. Our nation is now only partly committed to the space race. We have made a major national commitment to space exploration—the lunar landing and return program—but we need to increase our military space program. If necessary, we should modify our plans for scientific experimentation in space so that our military space program will derive maximum benefit from our overall space investment.

The military and civilian organizations responsible for our progress in space technology must have their interface tightened. Joint planning and control of NASA-DOD space programs and resources seem mandatory and inevitable if we are to avoid the possible security consequence of being second best in the field of space power.

I would like to review briefly some of our past actions and attitudes to illustrate how we sometimes tend to retard research and development in areas vital to national defense. Our society has generally responded sluggishly to the national-security implications of major advances in science and technology. After the famous Einstein letter was sent to President Roosevelt in August of 1939, more than two years elapsed before the atomic bomb program was initiated. We are all familiar with the long delay in arriving at the decision to build a thermonuclear bomb. Similar delays have occurred in many other fields of advanced weaponry, including the development of the intercontinental ballistic missile and the implementation of a major electronic continental defense system.

Ten years ago the feasibility of space flight was clearly seen by many scientific experts. In 1955 our own country initiated its first space program—the ill-fated Project VANGUARD—but still we failed to see the full opportunity of the space age. In 1957 Defense Department executives directed that the word "space" be deleted from all defense programs. While we were abolishing space by bureaucratic edict, the Soviets were pressing forward with the development of the essentials of space flight, resulting in the October 1957 flight of SPUTNIK I.

The past delays, ranging from two to five years, between scientific and technological definition of a national-security breakthrough and the decision to exploit fully the new technological advances for the national security have been dangerous in the extreme. Another such delay has already occurred in the field of

space. We must urge our national leaders to take action so that this delay does not extend for another two to five years.

During the past two decades, breakthroughs in science and technology have changed the environment of our world at a bewildering rate. Many of these breakthroughs or advances have stemmed from scientific and technical developments motivated principally by military or national-security needs. Nuclear fission, nuclear fusion, rocket engines, jet engines, jet aircraft, supersonic flight, ICBMS, and the electronic advances ranging from radar to high-speed computers and miniaturized solid-state devices have combined to revolutionize our military strategy, forces, and planning. In addition to their military usefulness, these advances have yielded vast dividends for the civilian population throughout the world. On the other hand, wonder drugs, Salk vaccine, vitamins, and other revolutionary developments, which stemmed from purely humanitarian motivations, have proved to be of great military usefulness.

In the field of space technology there was essentially *no* motivation, either military or scientific, until SPUTNIK I. Even then there was only a reluctant and timid exploitation of the possibilities of space science and exploration. Today, in spite of the years that have passed since SPUTNIK I, our space program is still principally scientific, with only limited military motivation. Our presently planned space program does not hold great promise of improving this situation.

The current state of our military space systems indicates a need for a realistic attitude and more action in the area of the military use of space. The combination of the freedom of space, plus the power of nuclear energy, opens broad new possibilities of weapons systems, many of which are as yet only dimly understood. When we recall that in 1957 our national leaders were able to foresee no military possibilities in space, it is not surprising that we are still unable to visualize the full military potential of space flight. However, certain military systems and needs are beginning to emerge.

The line-of-sight vision of space vehicles provides a great military advantage in: (1) communication, (2) meteorology, (3) navigation, (4) reconnaissance, (5) bombing, and (6) defense systems.

Many possibilities exist for retaliatory space weapons. Some of

them are not necessarily desirable or stabilizing by present standards. Most of them are highly debatable in the light of present cost and technology. Future technological developments, however, may change this situation. Some of the possibilities are: bombs in orbit, lunar based bombs, manned boost-glide vehicles, and other retaliatory weapon systems yet to be defined.

One of our most urgent needs in the military space field is in the defense weapons area. We do not have adequate satellite acquisition, tracking, or identification systems to meet the threat posed by existing Soviet satellites. We do not have a capability to neutralize, capture, or destroy existing or projected Soviet satellites. No such capability is yet under development on an urgent basis.

Many of the technical needs of military space systems are almost identical with those of space science and exploration. These include manned spacecraft and space stations. Most importantly, they include acquisition of a mastery of basic space capabilities fundamental to the development of future military weapon systems. These underlying and basic capabilities are: (1) ability to orbit, maneuver, rendezvous, de-orbit, re-enter, and land; (2) ability to support sustained manned space flight; (3) guidance, navigation, and communications systems necessary for deep space operation; (4) ability to transfer men and material between spacecraft.

Other military uses of space include decoying and concealment, nuclear tests in outer space, and arms-control surveillance and communications systems.

The central need of our space program is a variety of large, reliable boosters which will produce adequate (and even excess) boost for our military and scientific needs. Some of our big-booster military needs appear to be (1) 400,000 to 10,000,000 lbs. of thrust; (2) earliest attainment of 800,000 to 3,000,000 lbs. of thrust; (3) extremely high velocities (100,000 to 500,000 feet per second) for maneuvers, military load, etc.; (4) high reliability for repeated manned use; (5) standardized launch vehicles and techniques capable of meeting sudden and repeated launch needs of military operations.

Many of these military booster characteristics are identical with or close to the present and projected NASA program objectives. Many are not. Military emphasis on new engine cycles, solid-propellant boosters, and nuclear propulsion systems seems a necessity. A clear understanding that military big boosters are an urgent

requirement for the national security must soon be reached at all levels of the government. Most of all, the United States military space program requires policy guidance and decision from the highest levels. Direction is urgently needed with respect to the increased size of the military space program. We also need better management techniques in order to increase the military fallout from the massive scientific space programs, particularly the lunar landing and return project.

The specific programmatic deficiencies, other than the need for big boosters, appear to be: (1) Tracking and identification networks are not suitable for the present or projected military threats fom space. (2) There is an absence of emphasis, or there is inadequate emphasis, on space defense systems, particularly satellite neutralization, destruction, and capture. (3) There is insufficient emphasis on learning basic capabilities of rendezvous, maneuver, re-orbit, re-entry, navigation, and man in space.

The President's commitment to a major national effort in the lunar project provides only partial assurance that we may surpass the U.S.S.R. in space. The full force of our missile and space resource is not yet being focused upon gaining superior power in space. Additional decisions must be made by our national leaders. These necessary decisions appear to be: (1) to make a major increase in the United States military space program; (2) to accelerate the national booster program and change it so that militarily useful large boosters will become available much sooner than now planned; (3) to establish a joint military-NASA planning and control entity for the massive and expanding national space program.

13 POLITICAL EFFECTS

OSKAR MORGENSTERN, *Professor, Econometric Research Program, Princeton University*

It is very difficult to make positive statements about the political consequences of space exploration. We must acknowledge that there are two kinds of effects of a political nature —domestic and international.

I shall quickly dispose of the domestic effects, for I believe they are minor—almost negligible. Certainly they do not matter much, either in Russia or in this country, except for the consideration that space exploration is expensive. But we have become so accustomed to vast expenditures of monies that the expense is not an issue at this time. Besides, we have no real choice in this matter. The space race is on and we are committed to it.

Some of the arguments about space exploration one hears today —that it is expensive, wasteful, and adventurous—must have been used at the Court of Ferdinand and Isabella when Columbus tried for eight years to get sufficient money and equipment to sail across

the Atlantic (and discover what is now America). It was probably pointed out to Columbus that there were more important things to do inside Portugal and Spain than to set out on his uncertain venture. But he chose to minimize the domestic issues for what he considered more important matters. Following the philosophy of Columbus, we, too, must discard internal political problems, for they do not significantly alter the argumentation in favor of the space program.

Moving now to the international political effects of space flight, I will make a simple observation: the fewer the conflicts between nations, the better the chances of their arriving at agreements. Similarly, the fewer the conflicts between nations, the better the chances for enforcement of these agreements. In other words, the more vital the issue is to the nations involved, the less chance there is of arriving at working agreements, because the motive for achieving such agreements is lacking.

We can see this pattern in examining the agreement about the Antarctic, which was made by all nations, including Russia. This example is often brought forth by people who think it would be just as easy to make similar arrangements for space, but I believe the comparison is faulty. The agreement is working well because the issues are not really vital to the nations involved. Antarctica cannot compare with what space offers in the way of problems, prizes, and future potentialities. Such a comparison overlooks the unknowns and discounts the benefits we expect from space exploration. The greatest of these are not in the military area but in the area of scientific discovery. These great discoveries will span and affect the areas of economics and politics, and, of course, the military. Great complications will arise because of the implications of these discoveries; as a result, agreement will be extremely difficult.

Today nations are not able to separate the civilian from the military components of space flight and other scientific issues. We clearly see this phenomenon in our research, development, and philosophy on nuclear energy. In this area, the military and civilian aspects are so closely interrelated that it is very difficult to separate them. The result has a direct bearing on our international political position concerning the control of nuclear energy and fissionable material.

I believe also that space exploration and the possible discoveries therefrom will develop faster than the concepts and techniques

of dealing with them. This lag between a scientific discovery and ability to cope with it politically is an oft-noted, fundamental phenomenon of our times. One of the basic problems, then, is the setting up of political arrangements to safeguard the results of space discoveries so that they may not be turned into a danger for the human race or to the monopolistic advantage of one particular country. Unfortunately, as yet, I see no way in which this problem will be solved.

Another factor is that our leaders must realistically assess the reliability of those with whom we enter into agreements. Time and time again it has been proved that the Soviets are not to be taken at their word. We are aware that they were only recently sitting with us at a conference in Geneva. They appeared cooperative on the subject of stopping nuclear tests, but we know now that at the same time they were really months along in preparation for resumption of tests. When ready, they broke off negotiations and resumed testing. How can one negotiate in confidence under such circumstances?

Similarly, the United States made proposals, even before SPUTNIK I was launched, for an international arrangement on space. We received not even a reply. After the first SPUTNIK went up, our proposal was rejected. At the time of the rejection Russian scientists participating in an international meeting in the United States made very friendly noises about the necessity for space regulation and control. But while the scientists were attempting to reach an agreement, on the political scene the governments acted differently. The Soviet Union is a country which does not even communicate scientific observations in space accurately to us. For instance, it was said at first that Titov felt very well when he was orbiting around the earth, but now it is known that he was quite ill during a good part of his trip.

Another reason for the difficulty of achieving a working agreement is the lack of clarity concerning the differences between military and civil applications in space. Let us take the satellites, for example. It is obvious that satellite observations at night can be used either for weather information or for military intelligence. Since the only major space powers in the world are hostile to each other, the prospects of an arrangement on satellite observations seem very dim indeed.

We have had no significant success in dealing with important

issues by means short of international war. We have wars all the time. If anything, the space race is turning into an intensification of the arms race. We have not been able to control conventional weapons. We have not succeeded in providing any controls whatsoever on nuclear weapons, although we are in far greater and more imminent danger from this source than from the space race. Why, then, should space control be simpler than control of nuclear weapons?

If we project this situation into the future, the difficulties of space control increase.

Furthermore, we must realize that agreements without enforcement are meaningless. Every agreement must somehow be enforced by public opinion and by the police or by some nation or group of nations. But if the two major powers, the only ones that could provide adequate enforcement, are hostile, where is the prospect of agreement? Conceivably the many non-space powers on the Earth might be able to force the two super-powers to conform to some agreement, but I doubt that there is any real prospect of this. The problem of agreement will intensify if it develops that exploration of space is vital and promises to yield enormous prizes, as I think will be the case.

Another facet of this problem is that many agreements which have been and are being discussed are passing through various phases. For example, there is much legislation on the problem of overflight. A nation can control its overflight territory only by shooting down planes that violate it. This indicates that a country must have power in order to make the enforcement meaningful. At this moment satellites may cross over countries without being challenged. Currently there is no legal question involved, because no one yet has the power to shoot them down. However, that will certainly become possible in the future, and it will cause nations to push their zone of sovereignty farther out into space. Of course, it cannot be pushed out indefinitely, because in the course of the Earth's rotation on its axis and its revolution around the sun, the space above any country sweeps out a rather appreciable part of the Universe. Would each country then claim that part of the Universe, or even merely the Moon or the Sun? This, of course, is a reductio ad absurdum, but it points up the problem.

Many of the technical aspects of space exploration are really political questions. For instance, if we had the capability of produc-

ing satellites that could bring down other satellites, at what point would we decide to do so? We have the same problem today when hostile submarines appear, perfectly legitimately, let us say 100 miles from our shores. Are we going to sink them? At what point should we do this: when they first appear, or when they commit an overt act? We do not yet know the answer to this relatively simple question. The same type of uncertainty, of course, will arise in future space situations.

Finally, then, technology and its resulting race for space are running beyond the development of realistically enforceable agreements. The basic issue is this continually widening gap between the speed with which new scientific and engineering phenomena occur and the speed with which we invent workable political controls for these new developments.

14 INDUSTRIAL ECONOMIC EFFECTS

DON G. MITCHELL, *Vice Chairman of the Board, General Telephone and Electronics Corporation*

I ASSUME that a businessman like me is included here to remind everyone that while we are occupied with exploring space, there are major problems here on Earth that also require our attention.

As the result of research on the cost of space-flight exploration, we find that the money involved over the next ten years may be conservatively estimated at $50 billion. I wonder where everyone thinks this $50 billion is coming from? If the answer to this question is, "The Government is going to put it up," I remind you that the Government does not have any money. The only money the Government has is what it takes from you and me and the businesses and industries we work for, in the form of taxes. So the first economic impact of space flight is that it requires that we have a sound and prosperous industrial economy. If that does not exist, there will be no $50 billion for space exploration.

I am all in favor of having a sound, prosperous economy. I am also in favor of $50 billion. I shall try to point out how that $50 billion can be capitalized by making our "sound prosperity" even sounder and more prosperous. Industry in this country puts a total of some $10 billion a year into research and development. I have been making speeches around this country for ten years, saying we have to double that figure.

We are growing very rapidly. We have a continuously increasing standard of living. At the same time we have competitors abroad who are getting better at competing with us, because in some cases their equipment is superior to ours. Because Western and Central Europe were practically destroyed a few years ago, they were rebuilt with new industrial machinery, which is fast, automatic, and good. We in the United States have also installed a lot of new, fast, automatic, and good machinery in our industrial plants. But since our factories were not destroyed by war, we were not forced to replace all our equipment. This means that some of our friends abroad have better machinery, faster machinery, more economical machinery, and more automatic machinery than we do. Yet we must stay out in front in order to better our situation and to keep our economy rolling.

Space flight is giving us an opportunity to maintain our technological leadership of the world. For the first time in history, we have a chance to speed up innovation and invention under a peacetime economy. Generally it takes a war to speed up research and development. Of course, "peacetime" is a relative term. I realize we are getting a considerable push from the military aspect of this peacetime economy. However, in spite of this military influence, we are conducting ourselves primarily in a non-combatant attitude. The value of this peacetime scientific advance is that it affects our whole economy and every individual, no matter what business he is in.

I will now take you on a three-minute space flight and point out how this flight influences you and your business. Let us start with the blast-off from a launching pad. There cannot be a rocket launch without high-energy fuels. The greatest impact of those high-energy fuels is not going to be in sending rockets skyward from launching pads; it is going to be the application of what we learn as we develop the fuels. Our industries will then apply our findings to good old ordinary transportation, heating, and all the other uses for fuels we have in this country. That is where our economy is going to benefit.

Having successfully launched the rocket, we now have to direct its course. To control it we have developed countless new devices, including new electronic computers. These instruments, developed for space flight, will have a direct effect on our lives during the business day. They will alter drastically our business methods and procedures, our office economy, and our automatic production recording. All these will be changed as we develop and refine the techniques of space flight control.

What about the components that go into this rocket? The bigger they are, the more they weigh and the less payload we can put into our rocket. We must learn to make the components smaller and more compact. What happens as the instrumentation gets smaller and smaller? One fine day we will be able to do amazing things. It is not crazy any more to think that each of us can soon have a little telephone instrument in his pocket. It will have a number, which might be the same as our social security number. We will get it when we are born, and we will keep it until we die, and no matter where we are on the face of the Earth, somebody can call that number and only our personal receiver will buzz.

We now have successfully sent our rocket into space. There is a man in it, and we have to keep him alive. It would seem that life-support in space would be a simple thing. All we have to do is figure out how much CO_2 a man gives off and see how much oxygen he takes in. We know there are certain kinds of plants which can utilize the carbon dioxide he exhales and produce oxygen so that he can breathe. We have to find a plant which will give the right amount of oxygen and take in the right amount of CO_2. But people are not alike in their rate of breathing. Individuals give off different amounts of CO_2 and require different amounts of oxygen. So we will have to build a special food plant or air plant for each person, just as we had to design individual reclining pads to fit the contours of astronauts.

There will also have to be food for the passenger. In order to give him the maximum nourishment for space travel, we must learn more about the food we eat. The ultimate effect of this research will be right down on this Earth, in new knowledge for the food business. Dollar-wise, this information will be many times more important than our use of it in space flight and exploration.

Now we have to get the rocket back. We don't know much about getting it back. I read that if the X-15 test pilot didn't keep his ship on a 15-degree angle while coming in, he and his ship would

burn up. He won't always have to do that, because we are going to learn how to make metals and alloys with coatings around them that won't burn up. Think what we could do with these materials back here on Earth.

Now suppose we had left our man up there, in a so-called stationary orbit. This brings up the communications business, because in the communications field we can bounce signals off that thing up there, or receive signals up there and then transmit them back to part of the Earth. I assure you that the economic effect of these satellites on the communications business will be much greater down here on Earth than it will be in all the space vehicles we ever send out.

What I am trying to point out is that there is no part of the economy, no part of our lives, which won't be affected by space flight and space exploration. I also want to point out that unless we keep mama and papa eating well here on Earth, there won't be any point in sending our boys out in space.

15 INTERNATIONAL COOPERATION

TUNIS A. M. CRAVEN, *Commissioner,*
Federal Communications Commission

As a member of the Federal Communications Commission I am concerned with the problem of how to relate international cooperation to space communication. I will limit my discussion to just one phase: international television broadcasting. By that I mean direct broadcasting from the studios in one nation to the homes of the people in all other nations by means of space satellites.

It may be necessary to introduce a small, sour note in this field of optimism. I know that many believe this new medium of communication will result in better understanding and cooperation among nations and hence lead to universal peace. Indeed, I am informed that some of our leading research organizations believe in this hypothesis. They are apparently willing to spend millions of dollars in research to provide direct international television broadcasting to homes in other nations by means of space satellites. To

do this they suggest the use of some of the existing VHF television channels.

At first glance, history supports the thesis that improved communications result in better mutual understanding and greater cooperation among nations. But in terms of facts and actions this theory has proved to be unrealistic. Despite the efficiency in international communications, we find there is greater misunderstanding and worldwide suspicion than ever before. This leads to the conclusion that efficiency of communication in itself does not insure international understanding and cooperation. It now appears that the desire of the peoples and their governments to learn about and understand one another must come first. Until this is realized, international television broadcasting direct to the homes of the world may fail to achieve the objectives so earnestly desired by all of us.

At this point let me emphasize that I am discussing direct broadcasts into homes, not the relay of television programs via the local television networks of other nations. Also, I assume that direct broadcasting is entirely feasible from a technical standpoint.

Exploring this aspect of international cooperation further, let us start with the United States. To orient your thinking, I propose three questions for consideration.

First, are we willing to cooperate with other nations by changing our television technical standards to conform to the necessities of the worldwide system? Please note that each nation has a different set of standards at the present time.

Second, are we willing to surrender the television channels now used by our domestic television system in order to receive programs directly from other nations?

Third, are we willing to adjust our listening habits to the time differences between this country and other countries throughout the world?

There are myriads of other problems, but let us confine ourselves to the realistic analysis of these three questions.

First, the conversion of our television technical standards to conform with the requirements of other nations could cost the United States public billions of dollars. From the practical standpoint, the people of the United States would not react enthusiastically to such a change. They would have to be convinced that the new worldwide television service would contribute in a compelling

fashion to their welfare, and would result in better understanding and friendship throughout the world.

With respect to the surrender of television channels now used for domestic and local programs, it is most doubtful that the United States public would decide to surrender this service. Therefore the worldwide system would have to be accommodated in another portion of the radio spectrum. This would require either extra television receivers or all-channel sets. I submit that it is doubtful that many people would want to make the extra investment. This would be particularly true if another method for distributing international programs were available.

We all realize that time differences between various parts of the world constitute a serious problem in broadcasting live events as they occur. Obviously delayed broadcasting would be a necessity. While delayed broadcasting could be accomplished by means of a complex satellite transmission system, I suggest that it would be more economical to use advanced tape-recording techniques and distribute the tapes by high-speed jet airplanes to the main stations in the various nations.

If my analysis has any logic, it appears that practicalities alone dictate that direct television broadcasting by means of high-powered communications satellites might not be a factor for improving understanding among the people of the world. I say this in spite of some of our scientists who firmly believe this would occur.

It seems more feasible to use either tape recordings or satellite relays to the domestic television broadcasting distributing systems of each nation. Of course, this would reinforce the pattern of usage of each country. Some governments would still be in a position to regiment the amount and kind of information they permitted their public to receive. The controlling factor in a worldwide television system would be the willingness of governments to encourage the exchange of information by means of the most modern communication systems. Only if this were done could we be assured that the result would be better understanding and cooperation among nations.

This brings me back to my original premise: namely, the significant factor in international communication is not the excellence of communications facilities but the practical use to which the governments of the world can and will put them.

16 EXTRATERRESTRIAL CONTACT

PHILIP MORRISON, *Professor, Laboratory of Nuclear Studies, Cornell University*

PERHAPS the most extraordinary piece of knowledge that contemporary science, 300 years old or more, has produced in men is one which contradicts most plainly the clear evidence of the senses. Yet this knowledge is thoroughly confirmed by such a complicated net of ideas and experiments that no one doubts it. This is our acceptance as fact that the white glowing disk in the sky which is the supporter of all our life, and the tiny sparkles that we see moving steadily day after day across the night sky, are objects of one and the same category, but viewed over different distances in space. We believe as fact that the light of the sun is the light of a star, and the light of the star is the light of a sun, diluted only by its passage through the volume of space.

Galileo first proposed and argued that they were the same. But this was not fully believed until Huyghens measured the distance to Sirius by comparing its intensity to that of the sun on the hypothesis

dear to all Copernicans in those days. Today we cannot doubt it. If we accept that, as we must, we may ask another question: Are the phenomena we see conspicuously near our star in any way distinct from the phenomena that go on near the other stars? Of course, we know of all sorts of parameters in which they differ, and we must use our best judgment to discriminate among these parameters.

Let us also raise these questions: Among the many stars, are there any with planets around them? And on these planets has the star produced a sufficiently long-lasting input of radiant energy in the correct temperature zone to provide for the chemical abundance and the molecular species abundance characteristic of the Earth? That means neither too hot nor too cold, without much change over billions of years, in a galaxy which is passing 20 billion years old. It also means that there must be solid targets in the condensed matter around those stars to receive the input.

Please understand that we have no certain knowledge that any of these conditions have been fulfilled. We do not know in detail that any planets exist. But we can easily make the negative observation that if there are planets comparable to the planet on which we live, we have no evidence for them yet.

We see another piece of inferential evidence concerning the existence of planets replete with the characteristics of earth in the distribution of the angular momentum within the solar system. Our star is matter which must have been distributed through space before the star gravitationally condensed. This matter must be marked forever with the angular momentum it had. Angular momentum cannot be destroyed, no more than can mass or momentum. But the angular momentum does not appear in the sun. It is in the planets. A good deal more than 99 per cent of all the angular momentum of our solar system appears in the planets, even though they contain only one-tenth of 1 per cent of all the mass of the solar system. The angular momentum was somehow transferred from the central star into the disk of matter that became our planets. It is not my purpose to discuss the means of this transfer.

If a star is new enough and bright enough, it has plenty of angular momentum. We know this from our observations. We can detect the broadening of spectral lines from a star's surfaces which indicates a high speed of rotation. But we find that stars which are old and mature somehow have lost their angular momentum, and have no more than does our sun. We know angular momentum can-

not be destroyed. Where has it gone? We do not know. It might have been spun off in gases which have been sent out into the galaxy. Perhaps so, but the inference is very strong, irresistibly strong, that among at least some of those stars, there must be planets rather like our own planets.

Figure 37 shows the proportional probability of occurrence of stars versus the temperature. This has been calculated by traditional methods. The curve shows the relative probability of long-warmed planets in terms of the temperature of their sun. There is low prob-

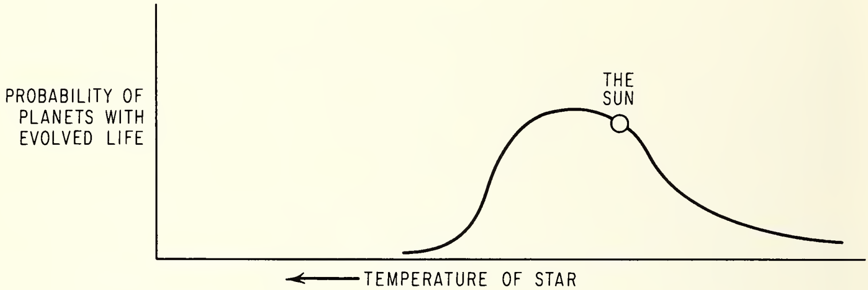


FIGURE 37. Stars in the middle range of temperature have a high probability of habitable planets.

ability of warmed planets at the very high star temperatures. Although these stars are very bright and warm, and could heat a great deal of space to the temperature of the Earth, they unfortunately spend their energy so fast that they have not lasted long enough to evolve life. Their characteristically short lives are indicated by their almost universally high angular momentum. Thus, at the very high star temperatures, we do not have long-warmed planets because the stars are too bright and therefore not long-lasting. They not only spin too fast, but they are also not very numerous.

What about the low-temperature stars? These are very faint and very long-lasting. However, they warm only a very small volume of space, and planets could hardly be maintained in the liquid-water phase unless they were very close to the star's surface. Yet these stars are very numerous, and this factor has been considered. All these factors—temperatures, spins, longevity, and population—have been taken into account in the estimation of the long-warmed planet probability curve.

In order to normalize this argument, there is a point, the sun,

which fits on our curve. This is purely a consistency argument, because I simply sought those environmental conditions that are like our own. It is nevertheless of interest that the sun sits quite satisfyingly on the broad peak of the bell of our curve.

Figure 38 shows a big galaxy. It is not our galaxy, but it is a view such as even the most intrepid of our rocketeers will not see. It is a view of a galaxy a few million light years away from ours, and we know from our studies that it looks very much like ours.

Figure 38. A galaxy seen edge-on.

Figure 39 is a schematized map of the galaxy, just to show you the geometrical relationship. This is the disk in which are most of the stars. On this map I have drawn a little cube. In that cube there are a *hundred thousand* sites for warm, long-lasting, stable, planetary systems like our own, based on the probability curve of Figure 37.

Suppose we now magnify this cube 20 times, to provide a little detail. This still doesn't do much good—there are still too many stars—so I magnify a tiny part of this second cube by another factor

of 20. This produces the final cube, in which all the possible sites of life are marked with *x*'s. One of these sites is the sun, a very successful site.

On this final little cube, to scale, I have drawn an interval which represents the path of an advanced ion rocket, powered by a fusion reactor, projected *three hundred years* into space from the earth (beginning in about the year 1990). Remember now, that this final cube must be divided by 20 to get the middle one, and that must be divided by 20 to fit it into the galactic scale. This tiny fragment is the region in which we are the *only examples known* to ourselves of a developed civilization.

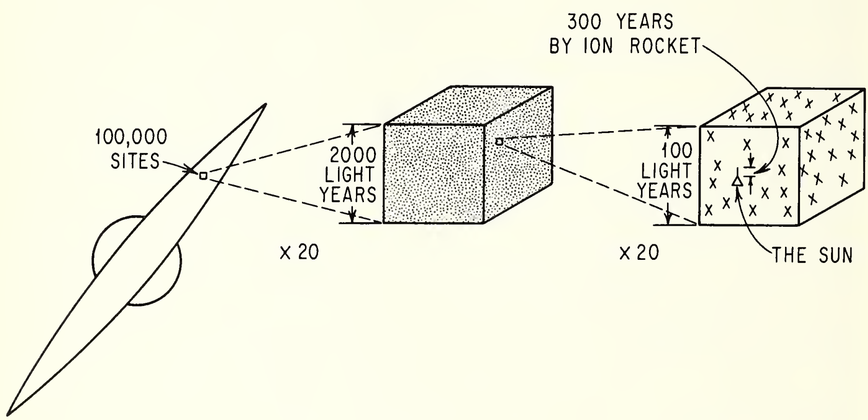


FIGURE 39. A small sample of the galaxy (*cube at right*), showing the probability of solar systems in our vicinity. See explanation in text.

I submit that on any Copernican basis—any basis which does not make us the center of the universe—we must have neighbors somewhere in the galaxy, to the tune of perhaps 10^8 or 10^9, which we have not yet seen.

Figure 40 shows us why these neighbors may be of interest to us. In my view, their discovery would be the most important philosophical and practical outcome of any conceivable interest in astronomy since the notion of day and night. On Figure 40 we see a curve showing the relative time variations of certain phenomena of our solar system. The curve showing the amount of planetary mass starts from some unknown but guessable beginning, levels off as of about 4.5 billion years ago, and is now highly stabilized.

With regard to the second curve, showing the growth of life on earth, we again don't know much about the beginning. There must have been a time when there was none. Life started, grew, saturated the oceans, evolved into some areas of land, and proliferated on land in the growth of trees and forests, which were particularly successful. At the top of the curve is a little spike which represents the even more successful development of a race of men. Notice that this curve rises rather more steeply than that of the planetary mass, but still not very steeply.

The third curve of Figure 40 shows the amount of fire on the Earth. It may seem that before there were men, there could not have been fire. Of course, this is not true. There was always flame, especially when the land was occupied by vegetation. At all times

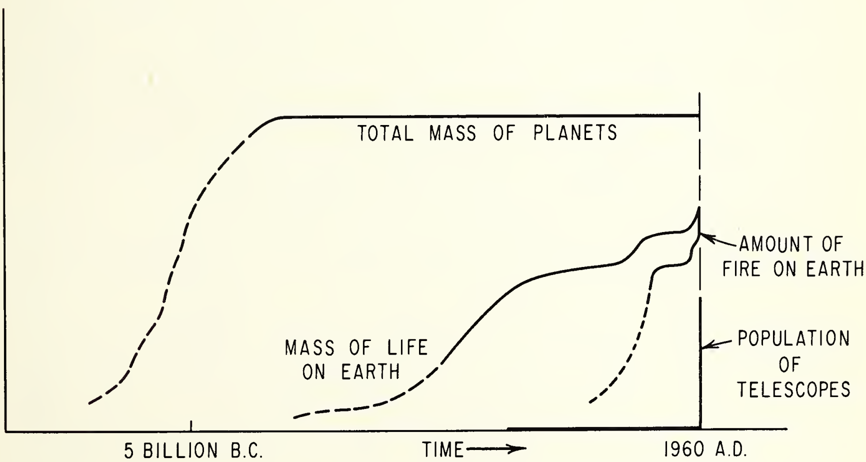


Figure 40. A simplified history of our solar system, showing the extremely rapid rise of science ("telescopes") in relation to the other significant evolutionary events on our planet.

there have been flaming gases from volcanoes and forest fires. The rough curve shows this estimate.

Finally, the last curve is a well-defined phenomenon—the population of telescopes on the surface of the earth. The curve is absolutely flat zero until it reaches an absolutely vertical spike, the sharpest possible rise-time. I simply cannot represent the short relative time of telescopes in the Earth's history with a proportionate curve.

These curves make it clear that the phenomena which we regard as those connected with scientific societies are enormously complex. I suggest that it is not a bad inference to think that they characteristically have a very short rise-time. Of course, we would like to know, in view of some of the rather gloomy prognoses for the world, whether or not this rise-time will be matched by an equally sharp decay.

In all seriousness, I do not believe there is any evidence to indicate that the time scale should not include the rise of men as a species, which is about a million years. I would like to think that within another million years we will still see an existence which will be recognizable as having descended from man. If this is true, then it follows that at least some of the hundred million or more possibly inhabited sites in our galaxy possess populations of telescopes and the rest of the science to go with them. What is their time basis with respect to ours? In a galaxy 20 billion years old it is most unlikely that they are synchronized, and since the rise-time of their scientific capability is so short compared to the plateau of any other parameter, we must expect that a great many of them are enormously advanced on the scale of civilization.

In that case we may think they will be interested in communication with their neighbors. In my view they have already maintained communication channels with their neighbors for a very long time. They understand extremely well that there are others around with whom they do not have communication. I believe they have long been operating not only national television channels but transgalactic channels of high complexity in information content, to which we are not yet tuned in.

How shall we tune in? It seems to me perfectly clear, on the one hand, that to send out signals indiscriminately is foolish. Our means will barely permit us to reach the nearest targets, the nearest possible sites. Their means, if they exist at all, must obviously be very great. Let us, therefore, listen.

To travel out to them ourselves, I am sorry to say to the American Rocket Society, is a most forlorn hope. I would not fund for a nickel any project to make a transgalactic space transportation device in view of the scale I plotted in Figure 39.

There is only one velocity I would trust· This is also the best and most economical velocity for transfer of signals or information: the familiar velocity of light. We have already produced beams

of radiation and of objects which carry splendid amounts of information at that velocity. I hope that it is to these we shall be paying increasing attention.

I have emphasized that we should assume a somewhat passive role in intergalactic communication because it is much more difficult to transmit than to receive.

Also, we should look or listen, but not move, because we cannot move to any appreciable degree.

However, there is one enormously important experiment right around the corner whose success or failure would be, for me, an impetus to considerable effort to try to tune in on the good tidings that may be out there. This experiment is a near-fly-by, or better yet, a soft, instrumented landing on the surface of our neighboring planet Mars. This is not far off. Either the United States or its rival across the ocean will succeed in this, certainly before 1970 and possibly sooner. When we do, we will surely provide, among the many instrumented channels, a device which can confirm the strong but inferential evidence from telescopic observation that some kind of life exists on Mars. It may be some kind of flora. I believe this is important, because at present I cannot answer anyone who may ask, "Do we know that there is anywhere, in the whole of the universe, another example of a living form or a technical civilization?"

We earthlings may be a unique accident, an accident whose moral and theological applications I leave to many writers. As a physicist, however, I have been taught to believe that while *one* example means nothing at all, *two* is pretty good statistics.

Therefore I submit that if we find one other example of life, this is the most important experiment that rocketmen could make. When the first positive information about life on another planet arrives, up will go the listening antennae to hunt for signals. These will be sought not from Mars but from one of the analogous planets of the remote billion sites in our galaxy. I am perfectly sure that somewhere on one of those sites populations exist with solutions to the problems that my predecessors have not been able to solve.

GENERAL DISCUSSION

GARDNER: I would like to return to the comments made by Mr. Mitchell. These concerned the need for a sound and prosperous economy and the problem of supplying $50 billion for military and civilian space flight while still having a sound and prosperous economy. I infer from Mr. Mitchell's remarks that he believes this can be done. To me, "sound" means alive and free, and "prosperous," somehow, means safe.

In the context of my previous remarks concerning the grave military implications of space flight, I would like to add one small note of history· On August 2, 1939, Dr. Einstein wrote his famous letter to President Roosevelt. In the blurring of history, many of us believe that this immediately caused the atomic bomb project to be born. This was not the case. The definition of scientific possibilities described in Dr. Albert Einstein's letter was not converted into a weapons project until well over two years later. As a matter of fact, it was not until December 6, 1941, that a serious meeting

took place to define the organization for a bomb project. It may be that the bomb project would not have gone at all well if Pearl Harbor had not occurred on December 7, 1941, a day after the decision to initiate the bomb program.

In general it takes two to five years of delay time for us to form political decisions to assign national resources to the areas defined for us by scientists. It seems to me that we have already had this delay in the case of military space. We cannot afford an additional delay of one or even two years before we have a major increase in our space program.

Mitchell: Mr. Gardner, I do believe we can have $50 billion in research and a prosperous economy at the same time· I happen to believe that it can be done better and a lot more pleasantly by letting business make the money and then pay out a large chunk of it in taxes than by taking all the money and giving us back a little.

Morgenstern: I would like to add a word about the meaning of space exploration. I do not think it means the establishment of better television systems for the world. Advances in technological equipment do not necessarily mean improved understanding between nations. I think what really matters in space exploration is that we would acquire, not satellites, not weapons, not bombs, but entirely new laboratories. These laboratories could produce scientific techniques of which we cannot dream at present. It is conceivable that some of the nations would be drawn together in the course of space research and discovery. This cooperation might result in the avoidance of wars which might otherwise have occurred.

> Question: The most ambitious United States space goals are (1) to place a few men on the moon and (2) to send research probes to the nearby planets. Is it possible that the U.S.S·R. space goals are significantly more ambitious?

Morgenstern: I do not believe it very likely, although we have no real way of judging.

Doolittle: One sense of this question might be: "Is it possible that

the U.S.S.R. space goals are more militarily oriented?" I personally think they are.

> QUESTION: Is there a need to continue the organizational separation of the military and civilian space efforts?

GARDNER: There is sometimes a need to unscramble an egg, but it is very difficult to do so. We do not have time to go back and recast yesterday's thinking. We have to make do with the organizations substantially as we have them. We may, perhaps, have to invent additional groups and procedures to supplement the existing organizations if they should not prove adequate.

> QUESTION: Do you believe that the speed of light cannot be surpassed? Is this a finality?

MORRISON: Nothing is a finality, but this law lies in about the same domain as the conservation of energy. When a perpetual motion machine has been produced, then I will consider violating the velocity of light. It certainly could be that a brand new outlook or discovery of an unprecedented kind might manage it, but we have no indication that this is the case. Indeed, the special theory of relativity in all its details has passed from the physics laboratory or philosopher's study into the domain of heavy engineering practice, as a half-dozen large-scale accelerators spotted around the world demonstrate. Despite the enormous integrated impulses brought to bear in these devices, we cannot get particles to travel faster than light.

> QUESTION: Can the United States afford the complex, highly maneuverable space force Mr. Gardner has outlined? Would not a system of reconnaissance satelllites, ICBM's, and anti-missile missiles be equally effective and economically more feasible?

GARDNER: I thought I made it clear that I was not outlining a need for such a force as much as a need for the possibilities that were inherent in space. The kind of force outlined and the kind of strategic concept it implies would seem to be adequate by today's

cost-effectiveness standards and state of technological progress. However, even ten years ago you would not have asked this question.

> Question: What is known of any possible forms or types of life that might be sustained on any of the nearby planets? On what is this information based?

Morrison: All the information we have so far is based on reflections of electromagnetic radiation from the surfaces of these planets and satellites, either visible radiation coming from the sun or the little bit of microwave radiation coming from man-made radar sources. Based on this information, we can tell something about the temperature and chemical regimes of at least the surfaces of all the sizable objects in the solar system, from Pluto to Mercury. Also, we have theoretical indications that smaller objects could not, unless they are artificial, preserve anything like the kind of conditions required. If we consider the widest possible span of the chemical forms of life we know, imagining that they have to use the hydrogen bond and atoms like carbon, nitrogen, and so on, the observed environments limit our possibilities to the so-called terrestrial planets —Venus, Mars, and Earth. Of these three, Earth, of course, has an abundant, elaborate biology. From the best studies in the microwave centimetric and infrared visible regions, Venus appears to have a temperature regime that looks most unsatisfactory. There is a small chance that there may be an opaque screen we haven't yet penetrated and that we are not yet seeing the surface of Venus. Most people now believe that the complex, half-stable, half-reactive compounds characteristic of a rapid-turnover biological system just won't work on Venus.

On the other hand, there is a variety of observations on Mars. These can be summarized by saying that there are localized patches, waxing and waning with the climate, which represent the binding on the surface of Mars of a fair concentration of carbon–oygen–hydrogen compounds at least as complicated as acetaldehyde. This is based mainly on infrared spectroscopy from reflected sunlight. It is very difficult to imagine a better mechanism for this than the presence of some kind of life. This would most likely be plant life, not necessarily like our own, but small objects capable of synthesizing and maintaining against the rather low atmospheric pressures an excess concentration of these rather complicated C–H–O com-

pounds. Of course, there are possible mechanisms other than plants. There might be minerals with chemical bonding which changes when the water strikes it, has the right infrared reflectivity, and so on.

We might allow ourselves to elaborate on this complicated hypothesis: Since we have seen living forms, and since the temperature regime of Mars is only a little worse than that of Tibet, it appears to me we have fair evidence there is something like plant life on Mars.

But that is why I want that probe to land on Mars' surface, reach out its long, sticky, mechanical tongue, pull some material in, and then chop it up into pieces to be examined through microscopes, chromatographs, and all the rest of the instruments. Then it could answer for us the question: Is this a complex, metabolizing, increasing system? I think the answer would be yes, and then I would have my two examples. I would then bet there are a hundred million more.

QUESTION: With regard to Mr. Mitchell's questioning of excessive government spending on space, is it possible to foresee a time in the near future when one or several space companies would grow large enough to develop their own complete systems, requiring only launch facilities from the government, and sell these systems to other companies or use them for their own purposes?

MITCHELL: No, I do not see that time coming in the near future. I have no objection whatever to our Government's spending the money for space efforts; that is not at all what I stated. I said I want the Government to let business make a sufficient profit so that it can provide the government with money in the form of taxes. The Government can use this income to back space exploration. In this way, the Government always gets money back when our companies spend it again, and so on. When money is turned over, it makes money for everyone.

QUESTION: Mr. Gardner, since our resources are limited, should they be directed toward roughly equal development of military offensive as well as defensive capability in space or toward development of

military defensive capability, coupled with scientific communications and ideological offensive capability in space?

Gardner: I disagree somewhat with the major premise upon which these offered choices are based. It is true that our resources are limited, but I would like to point out that many resources developed for our military ICBM program can also be used in the space program. But they are not being fully utilized at the present time. These are scientific as well as industrial facilities. The question offered two possible choices but there probably are several other alternatives. The question really asked is: What should our military strategy be for space?

It is very probable that it should be neither of these two questioned choices but a third or a fourth or perhaps a fifth one. In any event, I would not draw a sharp line by setting upon "either-or" situations. I believe we can develop some in each of those areas. I also have faith we here in the United States are capable of producing more of everything in space flight than we are now doing.

Question: Professor Morrison's picture of a large number of possible sites for intelligent life leads to the expectation that some non-terrestrial society should have learned how to communicate with us in our language and in our techniques by this time. But we have received no such contact or message. There appear to be four possible explanations: (1) Our planet is absolutely unique. (2) Communication is impossible. (3) All the planetary life systems started at essentially the same time. (4) All advanced life like ours is doomed to extinction once it reaches a stage of development such as ours. Which is the answer?

Morrison: I believe there should be *five* questions, and the answer lies in the fifth one: We just listen and we will hear. This may be next year. Radio transmission began not more than 75 years ago. Before that time the strongest radio signal in the world would simply not have been detected. We must ask the question as to how large an effort really can be made to find us. If we take the

view, as I do, that we are by no means unique, then our galactic friends have already found many, many previous civilizations. This is just one more, and possibly a Ph.D. in some department of anthropology will be granted for finding this one.

I therefore reject all four of the question's hypotheses. I think the most interesting, the one that makes this research so vital, is hypothesis No. 4, that there may be something intrinsically self-destroying about scientific civilizations. The measurement of our civilization's lifetime by the failure to receive signals after much investigation would be an extremely important justification for the whole program. Hypothesis No. 4 is therefore to be tested. I think it is very important to listen, and to listen with better and better means, so as to enable us to survey targets farther and farther away. At the moment we cannot exclude the hypothesis that very considerable efforts *are* being made to contact us from numerous stars—as many as tens of millions—in our galaxy. We would not have heard them. Only if there were many hundreds of millions, all trying, could we exclude this hypothesis, because the pioneer efforts of Dr. Otto Struve and Dr. F. D. Drake at the National Radio Observatory in Green Bank have given us the information that at least not *every* star is putting out a signal of great strength in a particular channel. However, this still is very far from being firm information.

I therefore suggest that we just wait, and we will see that none of the question's four hypotheses will be proved. I do not know how long we will have to wait; Professor C. F. Powell, of Bristol, says that this is an experiment for the centuries.

IV. The U.S. and the U.S.S.R.

EDITORS' INTRODUCTION

ONE of the aims of this report is to assess and explore the relative positions of the two nations most significantly committed to space exploration: the United States and the U.S.S.R. The unique importance of this assessment is in its authoritative clarification of the facts defining each country's position in the space race.

This section is designed as a series of questions posed by Mr. Clarke. The respondents to the questions have attempted to describe the policies and decisions that placed the United States in the position it now holds. The questions cover many facets of the space competition. These include the difference in the philosophies of the United States and the U.S.S.R., the differences in missions and vehicles, the veracity of the Russian technical reports, how the different processes of government influence the funding and de-

velopment of space-flight research, and the controversial aspects of the rendezvous technique.

The answers to the many questions make up the answer to the question, "Who is ahead?" The reply to this one final question may determine the future of the United States and of our democratic civilization.

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CLARKE: Because all astronauts must necessarily be optimists, we had hoped to have a panel consisting of Russian space experts as well as American space experts. For various reasons this did not materialize. I gather that the Russians could not get a visa to the Coliseum, but they *did* get a visa to 34th Street, because some of them were seen at the top of the Empire State Building a few days ago. As a result we have an indigenous panel to discuss both the United States and the U.S.S.R. programs.

Our panelists comprise one of the most distinguished groups that has ever been assembled on the subject of space. They are: Dr. Hugh L. Dryden, Deputy Administrator of NASA and one of the best known aeronautical engineers in this country; General Bernard A. Schriever, Commanding General of the Air Force Systems Command, famous for his work on the development of the United States missile systems; Dr. F. J. Krieger of the Physics Department of the RAND Corporation, author of the book *Behind*

the Sputniks and as knowledgeable on Russian work in this field as anyone outside Russia can be; Dr. Arthur R. Kantrowitz, Vice President of the Avco Corporation, well known for his work on nose cones and fundamental physics in the field of magnetohydrodynamics; and finally, Dr. Wernher von Braun, Director of the George C. Marshall Space Flight Center. My name is Arthur Clarke. I am a writer and the moderator of this panel. I am here because, unlike the other members of the panel, I am completely expendable.

Before I go on, I would like to introduce one other gentleman. In the history of astronautics, there are three great names. One is the Russian Tsiolkovsky, who laid the foundations of the theory of space flight at the end of the last century. There is the American, Dr. Robert Goddard, who in the 1920's designed and launched the world's first liquid-propellant rocket and is perhaps the greatest name in American rocketry. His name, of course, is perpetuated in the Goddard Space Flight Center. Finally there is Professor Hermann Oberth, whose books, published in the 1920's, discussed not only rocket propulsion but every aspect of the theory of space travel in great detail, and who directly inspired much of the European work in this field. Of these three great pioneers, only Professor Oberth is still with us, and I am very glad to see him here today.

Now, to discuss the United States and the U.S.S.R. space programs. A moderator, you know, in nuclear physics, has the job of keeping the reaction going but preventing it from exploding. I hope to do just this.

First I'd like to explore the difference in attitude toward manned space flight. What is the explanation of the apparent difference in the philosophies of the United States and the U.S.S.R.? From the very beginning the Russians have placed major emphasis on space biology, with the obvious intention of achieving manned flight. Yet in the United States, until recently, there has been great opposition to a man-in-space program. It seems to me that there has been more opposition in the United States than can be accounted for simply by the lack of suitable vehicles.

DRYDEN: I will be glad to start by denying the charge. From the very beginning of the United States space program, within both the Department of Defense and NASA, it was agreed that no space program for the United States would be complete unless it had, as

one of its objectives, the development of manned space flight. Project MERCURY was established the day NASA was born.

SCHRIEVER: I agree with Dr. Dryden on this. In my opinion, there has been no lack of interest in this country about getting man into space. We have been limited by boosters, and this has meant a limit on the payloads that we could place into orbit. This limit has had some effect on our ability to match the Soviets.

KRIEGER: It has been a part of Soviet philosophy to point out that the idea of manned space flight originated in the Soviet Union. By placing emphasis on manned space flight, the Soviets can paint a better picture of themselves and exploit the image to the rest of the world. They can thereby show that Communist countries are superior to the West.

KANTROWITZ: I think that one point should be made here, since we do not want to completely discourage our moderator. It is true that a different attitude has been taken in this country from that of Russia. Immediately following their first Sputnik, the Soviets concentrated directly on bio-astronautic flights, whereas this kind of thing has not been carried to the same extent in this country. We see in the United States much greater emphasis on practical or applied programs. These programs place less emphasis on the spectacular than has been the case in Russia, but they will give us an immediate, visible return.

VON BRAUN: I agree with the statements of both Dr. Dryden and General Schriever. The fact that we started relatively late in the manned space program was due mainly to lack of transportation, and not lack of intention.

CLARKE: What partly encouraged me to ask this question was the fact that until recently there were some influential voices in this country raised against manned space programs. They said it was nonsense, even if we could do it. I am glad to hear that these voices are not really either influential or representative.

DRYDEN: It is true that there are people in this country who question the purposes and values of manned space flight. Apparently

there are similar people in Russia, but we do not hear about them. It might be interesting to recount my discussion of this question with Professor Sedov. We were discussing cooperation in space programs, and Professor Sedov was ready to cooperate in the exchange of information. When we talked about cooperation in manned space flight, however, he said: "I am afraid that if we cooperated, there would be no program in either country."

CLARKE: As you will have gathered, Professor Sedov has quite a good sense of humor. I once remarked to him, "It is a pity that in the Gagarin film, the rocket seen taking off at the end of the film is not Gagarin's rocket; it is, in fact, a Russian IRBM."

Professor Sedov looked at me with his Mona Lisa smile and said, "Well, from a distance, all big rockets look the same."

The second question really follows the first, and has been partly answered. What is the Russian attitude toward automation for space exploration? Have any Russian spokesmen argued that machines should be used instead of man in space exploration? I am thinking of all these automatic robot probes now being designed for lunar or planetary investigations. Many of them do, at enormous expense, roughly the same job that could be done by an experienced prospector with a pickaxe.

KRIEGER: The Russian literature is replete with examples of this sort. You probably remember the tankette laboratory (or caterpillar tractor) for lunar exploration described by the Soviet scientist Khlebtsevich about eight years ago. Although this particular project has not gained terrific priority, people are working on it. Descriptions of it can be found not only in the Russian literature, but also in the satellite-country journals.

CLARKE: How authentic do you think these are? Are they just journalistic ideas?

KRIEGER: It is rather difficult to be specific. This project has been brought to the attention of the public for discussion by not only the top scientists but also the technical people who work in industry. These discussions take place in science clubs, museums, and so on. The press, too, has been focusing attention on this type of project.

I remember seeing a recent description of such a device in a Yugoslavian newspaper. The article stated that these devices are in production. But it is difficult to say how much credence we can put in these reports.

Kantrowitz: I remember that Dr. Sedov gave me a long lecture about the importance of doing things *without* a man in space—about everything that could be done with automatic devices. I did not pay any attention to it.

Clarke: When I mentioned this to Dr. Sedov, I referred to some of the surveyor and ranger projects. He shook his head and said, "Too complicated." But I am not sure exactly what he meant by this!

Schriever: I do not know what the Soviets actually have said about automatic systems. But we do know what the problem is in obtaining reliability in a missile and in obtaining reliability in a payload which has to operate for extended periods without manned maintenance. We also have made studies of some of our more advanced experimental aircraft, including the X-15, just to determine how many times we would have lost the vehicle if it had not had a man on board. I am not at liberty to say what that number is, but I can assure you it is considerable. I have no question in my mind whatsoever about the importance of man in future space operations.

Dryden: I think our Russian colleagues have produced automatic gadgetry of rather complex types in their machinery to photograph the other side of the Moon, and probably in their Venus probe. We do not often find out very much about Russian failures, but in these two cases we do know that they did have failures which could not be hidden from the world. The transmission system from the Venus probe ceased after a relatively short travel. In the case of the Lunik that took pictures of the other side of the Moon, conversations with some of their scientists informed us that the Lunik also carried scientific instrumentation which was intended to be turned on the *second* time around. But, as we recall, there were no further receptions from the Lunik. The story was given out that perhaps the power system had been hit by a meteorite. We have proof, in these

two cases, that the Russians have worked on rather complex devices. From these two instances we also know that they, too, have experienced failures, just as we have.

KRIEGER: The Soviets made quite a to-do about their photography of the Moon. They actually published a catalogue of the formations on the reverse side of the Moon. Yet nowhere in the volume is any mention made of how many pictures they actually took. It was not until just a few weeks ago that Professor Mikhailov told me there were only nine photographs taken; yet there are something like 30 pictures reproduced in the volume. Of course, the negatives developed in the Lunik device were transmitted on several occasions, but for a matter of almost two years the Soviets made no mention of how many pictures the device actually took. This tends to reinforce somewhat the idea that they cover up their failures.

CLARKE: There appears to be a minor industry in the United States dedicated to prove that the Russian space achievements are "faked." I am quite surprised at the number of people who still believe this. I would like to ask two questions: First, does anyone know of a single important case in which there is reason to doubt any Russian claim in this field?

DRYDEN: I have spent many hours before the Congress on this question. I have said repeatedly to the Congress that I have no doubt they have done substantially what has been claimed.

SCHRIEVER: My answer to this question is "No."

KRIEGER: We find by reading the Russian literature that their claims are substantiated. They make certain statements which can be followed up by examination of the facts. For instance, certain statements were made about the test shots of rockets in the Pacific. The actions taken during the course of the tests were in accordance with the statements made.

VON BRAUN: On the basis of what evidence I have seen, I have no reason to doubt the veracity of any of the claims they have made.

CLARKE: That seems to dispose of *this* particular matter! The second

question is this: Does the panel think that skepticism resulting from this belief has had a seriously adverse effect on this country's sense of urgency? If so, what can be done about it?

Schriever: This attitude may have had some slight effect before last year. I don't believe that it has had a seriously adverse effect on our current thinking, nor do I believe that it has *any* effect on the sense of urgency in this country today.

Von Braun: I have heard quite a few comments from people who just don't want to believe that the Russians have done these things. They are often greatly encouraged by the fact that their views seem to be shared by some newspapermen. I really believe that the press people who write articles filled with skepticism are rendering their country a disservice. It is always dangerous to underestimate the enemy. I think, in this case, there is absolutely no evidence that the Russians have faked their shots, or, as some people have implied, played video or sound tapes back from unmanned satellites, pretending that there was a man on board. I really think one shouldn't mislead the public in this way. It may have a damaging effect on our stature.

Clarke: I am really happy to hear such a unanimity of opinion. I hope your decisive statements will finally settle the matter.

I notice also that there is a kind of inverse effect about the kind of information people want to believe. When the Russians claim to have done something such as orbiting a man, many people say it is a fake, but when they admit that one of their vehicles has been destroyed, then a rumor immediately starts that there really was a man in it!

Now, I would like to deal with another piece of national folklore. The former chief Soviet rocket scientist, Dr. Tokaev, gave a lecture to the British Interplanetary Society in London. He quoted Stalin as saying to him, soon after the war: "This is absolutely intolerable. We defeated the Nazis, we occupied Berlin and Peenemunde, but the Americans got the rocketeers. How and why was that allowed to happen?"

Accepting this statement as true, how and why did the American public get the idea that it was exactly the other way around and all the "rocketeers" went to Russia?

DRYDEN: I haven't the slightest idea, unless this may have been a theory to explain the early appearance of SPUTNIK. I believe that the Russians have been working with rocketry for a very long time, and, while it was a great help to get key people from Peenemunde, that was not the major factor.

KRIEGER: It was largely a matter of choice on the part of the German scientists and engineers.

VON BRAUN: I think I could have explained to Stalin why the "Peenemunde rocketeers" didn't wind up in Russia. We just went West before the Russian Army came.

With regard to the contribution of whatever German engineers or scientists the Russians did capture and take into the Soviet Union, there is every evidence to believe that their contribution to the Russian space program was almost negligible. They were called upon to write reports about what had happened in the past, but they were squeezed out like lemons, so to speak. In the end, they were sent home without even being informed about what went on in the classified Russian projects.

I think the greatest single contribution by German rocket engineers to the Russian program was the war booty: the scientific libraries, secret reports, things like wind-tunnel models and advanced design concepts, and so on. They evaluated this material very carefully, incorporating it into the body of knowledge and into the foundations on which their space programs were built. This is really the essential contribution, if any, that came from German rocketry. It is simply not true that the Sputniks or the carrier rockets for the Sputniks were built by former Peenemunde men or any other German scientists in Russia.

CLARKE: I apologize for bringing up these rather old questions, but since they are still around, I thought it was important that this influential panel use this unique opportunity to deal with them.

About a year ago, Prime Minister Khrushchev said that the Russians would soon be able to orbit 50 tons. Does anybody have any idea how soon this will really happen? When will the United States be able to orbit a 50-ton vehicle?

DRYDEN: Until they produce the next step, we have no real basis

for estimating how soon they will be capable of orbiting 50 tons. One of the troubles with forecasting the future of the Russian program is that they have used essentially the same booster from the beginning. They have achieved some improvement in their upper stages, either by improving performance or doing a better job of matching, resulting in an increase in orbited weight from about 8,000 pounds to about 14,000 pounds, as I recall. But we have seen no major booster changes, and hence have no basis on which to extrapolate their future.

As to the United States, I'll let Dr. von Braun tell us how soon he thinks he will give *us* the means of orbiting 50 tons.

Von Braun: I would like to shoot that question back to Dr. Dryden by asking him how much money he is willing to give us to do this.

Dryden: We shouldn't air our internal problems here. Dr. von Braun spends something like 40 per cent of the space budget. I have sometimes teased him by saying that so far all we have obtained for it are some large structures built at Redstone and Cape Canaveral, and some noise in the neighborhood of Huntsville.

Kantrowitz: There is a possibility that the Russians already have the rockets to put 50 tons into orbit. They do have rockets capable of launching a man. If they also have the capability of putting several propulsion systems together, as we did with our saturn i, then they would need just seven of these rockets, each capable of launching seven tons, to launch 50 tons.

Von Braun: We have a project in the works now which will do substantially better than 50 tons in orbit. It is anybody's guess as to whether we will have this capability before the Russians place 50 tons in orbit. I think it is almost impossible to stay ahead of the other fellow in this kind of game all of the time; it is more like a leapfrog proposition. It takes many years to develop such a large rocket, and it may very well be that one of the two contenders has been ahead of the other for, say, two years, only to see that the other has been leapfrogging him in the meantime. This may result in a see-saw for quite a number of years to come.

Schriever: I would be inclined to agree with Dr. Kantrowitz. There

are two factors that are very important. First, although, as Dr. Dryden pointed out, the Soviets have apparently been using the same rocket for all their space shots, we certainly should not suppose that they have not been developing new rockets during this period. As a matter of fact, I am certain that they *have* developed new rockets. Second, they have never made claims, at the Khrushchev level, that they haven't followed up with reasonable promptness. It would, therefore, surprise me very much if they did not achieve a 50-ton vehicle in orbit in the near future.

CLARKE: My next question directly follows the previous one. Russian space scientists have often claimed that they have no trouble in getting the money and support they need. In the United States, on the other hand, leading scientists and engineers have to spend literally thousands of man-hours testifying before Congressional and other committees. How much of this is really necessary? I am reminded of one rocket scientist I know here who claims that he had to make 600 presentations of his project, and even then he did not get the money for it. To put it bluntly, and I won't blame any of the panel if they plead the Fifth Amendment, how much would the United States space program be accelerated if Congressional inquiries were abolished?

DRYDEN: If the Treasury would deposit $20 billion in the bank, we could accelerate the space program very greatly. However, in a democratic country I do not think this is likely to happen, for a great many reasons. Our appearance before the Congress, and the justification of our program, is part of the way we operate. In the long run it will accelerate our program if the Congressmen understand it, because it only takes a very few influential Congressmen who are averse to a program to hold it back.

I think our appearances are very much worthwhile. In a dictatorship, of course, this type of appearance is not necessary. If we speak specifically on *science* in space, I believe the space scientists in Russia are very unhappy. There hasn't been a successful *scientific* payload launched since SPUTNIK III. There have been no space-science experiments. The Russian program has been a sequential one —first, three earth satellites, the scientific experiments, including life science studies with the dog; second, a jump to the three Luniks; and third, the test series leading to manned flights. These included

vehicle tests and recovery tests (with three failures in six attempts, and a shift from long periods in orbit to a single orbit for the first manned flight). These were, of course, followed by the two manned flights.

However, we note that there has not been a single successful space-science experiment since the early Sputniks, although, as I mentioned, there were such experiments on one of the Luniks which did not operate because of a power failure. There were also space-science experiments on the Venus probe, which did not operate because of a power failure.

Schriever: I think presenting and justifying a program is a necessary part of our democratic system. The legislative branch certainly has to be included, because it appropriates the money. I have made many appearances before Congress, not only for space, but also for other research and development work. The Congress actually has been extremely sympathetic. It has supported research, development, ballistic missile programs, and the space program. I agree that there has been a trend in recent years to increase the number of committees, studies, and analyses, but this is more peculiar to the Executive Branch than it is to the Legislative Branch, and perhaps this trend might well be reduced. But as far as the Congress is concerned, I believe it helps a great deal to educate and orient the Congressmen who have the responsibility to the people in this country. I have found the Congress to be extremely helpful.

Kantrowitz: I have the impression that our Congressional committees in this area are a positive asset. Appearances before them have a definite value, because their inquiries require us to explain what is going on. The process of answering critical and searching questions often produces progress. One of the more valuable Congressional activities certainly is its role as overseer of the nation's space program.

Von Braun: I have spent many hours testifying before Congressional committees. As a taxpayer myself, I believe that there must be somebody to decide how my tax money is being spent, and Congress has that responsibility. Without popular support, the space program in this country would be entirely impossible. This means that the Congressmen and Senators elected by the public must have

an informed basis on which to decide the extent to which these programs should be supported.

In the Kremlin this is probably much simpler. If the top men in the Kremlin say they want an aggressive space program, all Khrushchev has to do is to push a button and assign the required billions of rubles to the space people. A democracy does not work this way. For that reason I have never considered my hours in the Congress wasted. We have received the finest support and understanding, and unless we continue to carry our stories to the Congressmen, this support would most certainly cease.

CLARKE: I believe I can sum this question up by saying that the price of democracy is that one must accept a certain amount of delay and even sometimes a certain amount of inefficiency. In a dictatorship, one can always go ahead with a project quickly, but sometimes it may not be the right project.

Now for another area of discussion. Many people have suggested that the key to space flight lies in the so-called rendezvous, or technique of assembling and perhaps refueling vehicles in orbit. This has been brought up several times in the Space Flight Report program. How much indication is there that the Russians are interested in such orbital operations? Or are the Russians more interested in building single enormous vehicles for their more ambitious space programs?

DRYDEN: There has been some shift in the meaning of the word "rendezvous." I think the word is used quite often without any real understanding of what it means. Dr. Kantrowitz spoke of simply multiplying the payload of one vehicle by the number of vehicles in order to put a certain weight in orbit. But the group examining this question has become appalled at the operational and logistic problems encountered if the number of assembling vehicles becomes very large. The deeper our studies went, the more they seemed to indicate that the smaller the number of vehicles that had to rendezvous, the better.

I believe Dr. Von Braun, among others, has mentioned that by using vehicles of sufficient size, a rendezvous of only two of them will provide us with a method of proceeding to the Moon. There will be many experiments conducted, both fully automatic and manned, to investigate the problems of rendezvous.

To the best of my knowledge the Russians have not made any experiments of this type. I believe they could not make them without our knowledge.

Von Braun: The investigation Dr. Dryden just mentioned was conducted on the basis of certain general ground rules. The paramount one is that the President has announced that he wants this country to land a crew of men on the Moon during this decade. There is no question in anybody's mind, I think, that orbital rendezvous is a definite possibility, that it is feasible, and that the problems can be solved. But when we examine the problem of placing a crew on the Moon from all aspects, we are confronted with a very practical question. This concerns not what is feasible, but rather what can be done most cheaply, most rapidly, and with the greatest confidence within the time available to do the job.

We have already discarded the idea of building four of our old SATURN C-3's to put the necessary 400,000 pounds in orbit. We have plans to build a bigger SATURN, called the C-5, which can carry twice as much payload into orbit, so that two units will suffice to put the moon vehicle together; or, should the lunar orbit rendezvous technique prove successful, a single C-5 will suffice. We may still disregard orbital rendezvous altogether and go the direct route, NOVA, which will have an equivalent orbital capability more than twice as great as the C-5.

We have decided upon orbital rendezvous to go to the Moon because it is the key to space flight in every aspect, but the question as to whether it is the most attractive way of putting a man on the Moon in this decade was an extremely difficult decision to make. I want to point out that we did not lose any time by postponing this decision until the end of 1961, because the governing factor in our capability has been the availability of the powerful rocket engines, particularly the F-1 and J-2 engines, which play key roles in *all* possible approaches. These engines are presently under development with our maximum degree of support, and holding off the specific airframe development until this time had no effect on the program completion date. This time was, we believe, wisely spent in investigating the different approaches very carefully.

Kantrowitz: Another possibility for the lunar missions is that of using the ICBM-type boosters for rendezvous. These ICBM

boosters now exist and can be produced in quantity. The big-engine development, therefore, ceases to be the pacing factor, and the pacing factor becomes just how quickly we can achieve rendezvous. Once this is achieved, we have the production capacity to turn out enough first-stage boosters to put weights of the order of a million pounds into orbit. We now have that kind of capability, and it seems to me that this approach would be a most urgent study to attack vigorously. But as far as I can tell, the studies to which Dr. Dryden refers are just various versions of large systems which all depend on these F-1 engines which, as Dr. von Braun says, are a pacing item. We really should examine the benefits to be gained from our capacity, which is not being used, to produce the relatively small ICBM boosters.

VON BRAUN: This matter has indeed been studied. If we keep in mind the figure of 400,000 pounds initial weight needed in orbit to put a crew of three men on the Moon, disregarding the possibility of lunar orbit rendezvous, we must consider something like 100 ICBM launchings to put that initial payload together in orbit. This becomes a logistic problem comparable to flying the Berlin airlift with Piper Cubs. Nobody will say it cannot be done, but it certainly does not appear to be the best way to do the job.

KANTROWITZ: If that were the quickest way of doing the Berlin airlift and we had the Piper Cubs, should we have waited until we developed DC-6's to do it?

VON BRAUN: When we consider the total framework of time available here, eight or nine years, I would put my money on the DC-6's.

DRYDEN: If I may add to this confusion, we have made studies of doing the lunar landing and return with the smaller SATURN C-I vehicle, by running through an actual development plan of the number of launch stands it would take, the time required to get them built, the kind of reliability expectation we might have both from mechanical and synchronization viewpoints, and so on. From the point of view of the people who have to get the job done, this looks like a nightmare.

KANTROWITZ: But wouldn't it get us further ahead to use vehicles

that the Air Force has made reliable by repeated testing rather than to go to new vehicles which are still to be developed and made reliable?

Dryden: The problem, as we've mentioned several times, is in getting a large number of vehicles to meet in space and joining them together in any finite period of time with any real reliability. The people who had the responsibility to study this in detail say that this is simply not the kind of project that they would want to undertake with any assurance of getting it done.

Schriever: I would like to comment on the rendezvous technique. It is one of the fundamental capabilities that we have to develop in space for many programs other than the lunar mission.

Rendezvous is one of our most important techniques to develop from the standpoint of national security. We cannot inspect other space vehicles without being able to rendezvous. We cannot dock against another vehicle without being able to rendezvous. It may very well be that one of the first really practical applications of man in space will be the maintenance of large space stations which will carry very large, expensive payloads, and rendezvous techniques are essential to this maintenance task. Rendezvous, inspection, docking, and transfer techniques are thus of extreme importance, not only to the lunar program, but also to programs required for security in the years to come.

Clarke: The rendezvous problem is the problem of one space vehicle overtaking another and coming to rest with respect to it. Yet solving the rendezvous problem seems an almost simple task compared with another problem now being tackled with a high priority, that of intercepting an oncoming ICBM at a closing speed of 20,000 or 30,000 miles per hour. If we can successfully do that, we certainly can creep up behind another space ship at about 30 miles per hour.

Proceeding now to another area, it has often been said that the United States has obtained and published far more in the way of scientific results from its earth satellites than has the U.S.S.R. To some extent it would seem to me that this is capable of quantitative proof. I would like to know if Dr. Krieger or anyone else can give a rough idea of the ratio between the numbers of United States and

U.S.S.R. scientific papers in the field; is it two to one, five to one, ten to one, or more? Of course, I am well aware that content is far more important than volume. A single paper on, say, the discovery of the Van Allen radiation belt is worth hundreds on perhaps more trivial matters. Are there statistics of any kind in this field, comparing original United States and U.S.S.R. papers in pure space science?

KRIEGER: I have not kept any statistics on the volume of that type of Russian material. However, I can offer this example: The Soviets publish a journal called *Artificial Earth Satellites* at irregular intervals. This journal contains from 10 to 15 papers per issue. So far only eight numbers of this particular journal have been published. After examining the contents of number eight, which came out late in 1961, we find that there is a considerable time-lag between the experiments and the publication of results. They are still discussing results obtained from SPUTNIKS II and III.

We can also definitely say that all Soviet papers are subjected to severe editing. The Communist Party runs everything in the Soviet Union. The best papers are articles on Soviet space flight which have appeared in *Pravda*, the official organ of the Communist Party. In the September 8, 1961, issue there appeared a highly illuminating one-and-three-quarter page article on Titov's flight. If we can expect the customary time-lag, there will be a spate of technical articles on the subject two or three years from then.

In direct answer to the question, I would say that the ratio of published works may be much greater than ten to one in our favor.

DRYDEN: There have been studies made in this area. They were reported in a memorandum issued by one of the space committees. This information was obtained from NASA studies made by Dr. Robert Jastrow. As I recall, the ratio is about ten to one, but I again want to caution against a criterion that uses *numbers* of papers as a measure of results. This criterion is not really a fair measure. It is not surprising that the Soviets are still writing about SPUTNIKS II and III. As I remarked earlier, they haven't had any flights with space-science experiments since then.

KANTROWITZ: I contend that we can draw very little comfort from the fact that our efforts in space science are apparently superior to

those of the Russians. My reason is that we are really practicing an old art. We find that in all old arts, American technology is superior to that of the Russians. What is now called "space science" in the United States is a small extension of the kind of laboratory work that has been done in nuclear physics, in plasma physics, and in astrophysics for a long time. We have now simply attached these old instruments to rockets and satellites. One must continually pay attention to the things that are essentially new in the space business. The things that are essentially new have to do with space *technology* and not space science.

Dryden: I do not like to see anyone run down those parts of the space program in which we *do* stand in advance: space science and applications to communications, meteorology, and so on. Some of these are areas which the Russians have not touched on at all. We do ourselves just as much disservice by running down these accomplishments, which are within the capabilities of our boosters, as we do by believing some of the fictions about Russians which were stated earlier.

Kantrowitz: I did not run our technology down. I insist that our general level of technology is so far beyond that of the Russians that they exceed us only in the very few areas in which the power of dictatorship has enabled them to concentrate. But we must not take comfort from achievements which are not related to our progress in the essentially new art of space technology.

Dryden: We should take no comfort from the fact that we started four years later than they did. I agree with you on that.

Clarke: Apropos of the Russians' early start, I would like to quote again from the paper of Dr. Tokaev read before the British Interplanetary Society. In this paper the author stated that in September 1947 his group presented the Soviet Government with the plans for a three-stage orbital rocket. Does anyone here know just what happened to that Russian space effort? I am quoting directly:

"Had the group been allowed to continue its work without interference from outside, the U.S.S.R. might well have succeeded in putting a sputnik around the Earth in 1950 to 1952, but for reasons which had nothing to do with the project itself, or our

technical qualifications, we found ourselves in a difficult position. Toward the end of 1947, our work was paralyzed. Some of us were compelled to seek refuge in the West; the others were arrested. The rest had to wait."

KRIEGER: That was a peculiar statement to be made by Colonel Tokaev. I have heard him lecture on several occasions and have read at least four of his books.

Colonel Tokaev's first book, *Stalin Means War,* was published in 1951, after he had defected to the West. In this book he related what had happened before his defection. Between 1943 and 1947 the Soviets had no long-range rockets. They were very much interested in some of the projects that were being studied in Germany and also in Eugen Sänger's long-range bomber program. As a matter of fact, they wanted to appropriate the men making these studies. Stalin actually gave orders to kidnap some of these men.

But in his later books and lectures Tokaev began to assume the role of chief rocket designer. He made a comment to the effect that the first long-range rocket bore the symbol TT-I. One "T" was for Tikhonravov, the pioneer rocket designer whose history goes back to the 1930's. The second T was for Tokaev. After he defected, one of the T's was dropped.

This all makes rather interesting reading, but I rather question its authenticity.

CLARKE: Do you know of any specific thing that happened to the Soviet space program in 1947? Why did Tokaev defect? Was there some big breakup in Russia?

KRIEGER: His argument was that he did not like the terror tactics that Stalin used. Pressure was being put on him to yield. He made some disparaging remarks about long-range bombers and rocket planes.

VON BRAUN: The world is full of frustrated geniuses and misunderstood inventors from all countries. These discussions speculating on what could have happened are usually pretty meaningless. It takes time for ideas to mature. It even takes time to develop the necessary supporting technologies. Usually good ideas materialize only when all the ingredients are really there.

Kantrowitz: It is important to re-emphasize the point that the pacing element in most of our space programs is the time it takes us to arrive at and make decisions. This delay is frequently longer than any other period involved.

Dryden: I offer a historical example to illustrate the difficulty of arriving at a decision. We recall that when Whittle submitted his ideas for a jet engine to the British officials, it was rejected as being unworkable. Even Whittle himself will tell you that was the correct conclusion for the state of the art at that time. It took growth in the availability of high-temperature materials and in the development of a compressor design before Whittle's engine could be made to work. In spite of the jet engine's being a good idea and a good thing to work on, the assessment made of the idea as originally proposed was correct for its time.

Clarke: There have been at least four major groups working on United States space projects: the Army, the Navy, the Air Force, and now NASA. Do the Russians have, or did they ever have, more than one space program? Is this the one possible reason for their lead?

Dryden: I don't think we know the answer. I have already referred to the seriatim nature of their space-program series. From talking with Professor Sedov, I inferred that he has nothing whatever to do with the manned space program. He is chairman of a commission in the Academy of Sciences, and does have a good bit to say about the science program· To the best of our knowledge the manned space program is probably a military project in the Soviet Union.

Krieger: My only comment is that there is one party in the Soviet Union, the Communist Party. Mr. Khrushchev is its boss and, according to Gagarin, the space flight program is his baby.

Schriever: I agree with Dr. Dryden: it is impossible to determine the exact organization of the Soviet research and development, including space development. Based on my analysis of what we have been able to find out, I believe that there is a single very high-level authority in charge of the space development program in the Soviet Union. This, however, is not an operating management authority.

The program itself appears to be carried out in a number of different agencies within the Soviet organizational structure. In other words, it is not a monolithic organization, but there *is* a clear and single authority. This is based on our last analysis of how the Russians organize their space research and development program.

KRIEGER: Several months ago a new state committe for the coordination of scientific research was formed in the Soviet Union, superseding an earlier one. The head of this committee is the man in charge of the Russian space program. Although both Gagarin and Titov allude to him in their biographies, first published in *Pravda*, they do not refer to him by name.

DRYDEN: One of the characteristics of the Russian program is the great anonymity of the personnel. For example, we know very little about the engineers and scientists who developed the manned space capsules. This is in sharp contrast with the situation here in the United States.

KRIEGER: Several months ago the Soviet Union awarded 7,027 orders of various sorts to people who participated in the space program. Most of them—all but seven high government officials—will remain anonymous for a while. Khrushchev, Brezhnev, Rudnev (Chairman of the State Coordination of Scientific Research), and Kalmykov (Chairman of the State Committee for Radioelectronics) each received two major awards, while Ustinov and Keldysh (President of the USSR Academy of Sciences) each received one.

KANTROWITZ: I think these comments highlight a deep trouble in our space program. In my opinion there is a falsehood right at the heart of our effort—that there exist two separate programs, civilian and military. The idea that these two programs can be separated to any degree is a serious falsehood and has done a great deal to cripple our space program.

DRYDEN: I do not agree. As General Schriever stated, the same technology does lie at the root of both civilian and military vehicles. But the basic motivations of the final application are quite different, and no amount of talk will make them the same.

Kantrowitz: You may remember, however, that when we wanted to build a lot of tanks during the war, we went to the civilian automotive industry and we got them.

Dryden: We also go to the aerospace business to build vehicles for the civilian space program, although because of the enormous cost of a proving ground, both NASA and the Air Force perform the launches for the civilian space program. It would make no sense to do otherwise. But this does not mean that the end objectives are the same.

Clarke: I live in Ceylon, which Americans don't seem to realize is a little island off the southern tip of India. When at home I am repeatedly asked to explain the discrepancy between the statements and the actions of the United States. For example, the other day President Kennedy said that we must try to preserve outer space for peaceful use. Yet if one is to believe the public statements from both sides, the only purely military payloads so far launched into space have been United States ones, the SAMOS and MIDAS. True, these are defensive military systems, but as far as we know, the Russians haven't launched any specifically military systems at all. When I return to Ceylon, what should I tell my friends?

Dryden: I am a supporter of the military space program, which is engaged in the application of space technology to military uses. I think that our country needs such a program. I have some sympathy for the point of view which says that the revolver of a policeman is an instrument of peace and not an instrument of aggression or of war. I think our military services are instruments for maintaining the peace. I therefore have some sympathy with the idea that we should not overemphasize the "peaceful uses" aspect of the civilian program, because our military services also exist to maintain the peace.

Von Braun: Mr. Clarke mentioned that he was not aware of any Soviet military space program. However, I know of one case involving a certain major of the Red Air Force named Titov, who flew right over Washington, D. C., in 1961. Whether or not that had any military undertones I am not prepared to answer.

DRYDEN: Our astronauts do not wear their uniforms, although they came from the military services. They, too, fly over other countries. I do not consider their flights to be military incidents.

CLARKE: I believe that when some bits of a United States rocket once descended on Cuba, there were suggestions from certain quarters that this was an aggressive act.

Incidentally, I saw the first Titov press conference on television. One of the first questions he was asked by an American newspaperman was whether the VOSTOK could have carried a bomb. He put on a great display of indignation at this suggestion. The Russian astronauts are very good actors.

And now for another question. When a new space project is tendered in this country, literally scores of companies submit enormously detailed brochures and proposals. For example, there were five detailed proposals for the APOLLO Project; I am only surprised that in that case there were so few. All of these proposals have hundreds of thousands of words and volumes and volumes of material. Each of these has to be studied in detail before one is accepted. I have even heard of cases in which the total sum spent by all the firms bidding for a contract was more than the value of the contract.

First, do the Russians do it this way? Second, is there any way in which this overlapping and duplication can be avoided?

DRYDEN: By the very nature of their economy I assume the Russians can't and don't do it this way. We have tried the method of noncompetitive bids. That is, we have attempted, on occasion, to simply select a company and give them the responsibility without competitive bids or competitive negotiations. However, as a rule we just don't do things that way in this country. It's not fair to the other 50 companies which did not get the business. They would be the first to protest that method of procedure.

SCHRIEVER: We have a free-enterprise system in the United States. In some aspects this places us strictly on the horns of a dilemma. Let me explain our predicament. There are always a large number of companies who believe they are qualified to do almost anything and want to be requested to submit bids and proposals. In order to save valuable time and money, in the Air Force we have evolved a

somewhat selective means of accepting proposals. We choose a list of companies we consider to be qualified for highly sophisticated work, and we submit requests for proposals to this list only. We keep close surveillance on the capabilities of the companies in this country and make numerous surveys in order to keep our list up to date. It is to the benefit of the companies themselves not to become involved in expensive preparation of proposals when they do not really have the capabilities for the kind of job we have in mind. We attempt to be somewhat selective, but at the same time we want to open up our work to the largest number of qualified companies available. It is a difficult task, and one which I don't believe we will ever solve completely.

This problem is one of which we are very well aware. I personally have stated on numerous occasions to members of the industry that I think they spend too much time making proposals, that they assign too many of their good people to proposal preparation, and that there are too many brochures which, in the Air Force, we call "cocktail brochures."

I think we are getting away from this. We are becoming more restrictive in the selection of contractors. I would like to see us reduce the number of proposals made by companies in this field. This is really a joint government-industry problem, and I think we would be far ahead if we could find the right solution.

Krieger: There *is* a limited amount of competition in the Soviet Union, at least in the aircraft business. There may be two or three designs that are submitted for consideration, but only one is selected. The groups that worked on the other designs just turn their attention to something else. This is probably true in missiles also.

Kantrowitz: It is clear that a certain amount of competition is healthy. One of the great advantages we derive from our competitive system is the opportunity to select from a number of contenders the one that has the best chance of achievement. This is part of our system. Of course, it is not perfect, and there may be a lot of waste on occasions, but this is nevertheless a natural method of selection.

Von Braun: I agree with Dr. Kantrowitz that the competitive aspect has its positive side which we should not overlook, despite

all the waste that obviously goes into too much proposal preparation and proposal evaluation. While making a proposal, the company builds up its capability in that field. Even if it should lose one proposal, it may come out best on the next try. Proposal-making thus becomes a method for putting teams together. I do not say that this is the most effective or the most economical way, but it certainly works.

There is another aspect to this subject, particularly with regard to the United States' stature vis-à-vis the Russians in the space field. I had a talk with Dr. Sedov of the Soviet Union, who in 1961 was president of the International Astronautical Federation, in which I asked him this very question: "How do you, in the Soviet Union, substantiate the claims of the various proposal-makers? For example, companies claim that they can build guidance systems with fantastic accuracy, or that they can do a certain job within 1,000 manhours, and so forth. Who evaluates these proposals to decide who gets the jobs?"

He gave me a very interesting answer: "Very unfortunately for us, we don't have that dilemma. We don't have enough competition in the Soviet Union, and we have to prod our development teams continuously to persuade our own men to start new approaches to a given problem rather than stay within the well-proved grooves."

In other words, wherever there is a new possibility, a new opening, or a new avenue for solution of a problem, we in the United States can rest assured that immediately there will be a company trying that approach. The Russians apparently keep to the well-proved ways that guarantee success. They are utterly reluctant to start something new.

CLARKE: It is often said that secrecy is one of the greatest obstacles to scientific progress. The Russians obviously have a fantastically good security system. I sometimes wonder if it interferes with their own efficiency. For instance, I was involved in a situation in which it appeared that Russian space scientists did not know certain aspects of their own program. The day after SPUTNIK I went into orbit, all of us who were attending the I.A.F. Congress in Barcelona were astonished by its enormous weight of 184 pounds. Dr. Masevitch, head of the Optical Tracking Program in the Soviet Union,

flatly denied to me that the weight could be 184 pounds. I said, "Well, that is what *Tass* says."

"*Tass* is wrong," she said.

That is something I never expected to hear a Russian say! It appeared that she just did not know the weight of the satellite at that time. I mentioned this later to Professor Sedov, and he had an alternative explanation. Dr. Masevitch, he said, knew that all the SPUTNIK I hardware that went into orbit weighed about five tons, and probably she was thinking in that direction rather than thinking that it could not be as *much* as 184 pounds.

Anyway, this set me thinking about Russian security and its possible effect on their own efficiency.

KRIEGER: Your experience is typical of many examples that could be cited in this area. Tokaev brought this out in a lecture that he gave in this country. He spoke of the long, involved procedure a Russian scientist or engineer must follow in order to obtain copies of reports of Russian origin or from the United States. Security is very strict, just like membership in the Communist Party. In order to get details on related work, a scientist or engineer must first be cleared by the party and then by the controlling agency. This is espicially bad in a geographical sense, because some of the work is decentralized, and coordination must be arranged. The Soviets have a tremendous problem here.

SCHRIEVER: There is no question about the fact that excessive security is a highly inhibiting factor in the advancement of technology. If it is as bad in Russia as Dr. Krieger points out, it would make me very happy.

DRYDEN: I have no intimate knowledge of the Russian security system. I agree with General Schriever that excessive secrecy is certainly bound to handicap any project. But sometimes I wonder whether the high degree of openness we follow here in the United States is not also somewhat of a handicap in the sense that we have not yet become accustomed to what's involved in development projects. In all of our activities, very little goes on without a full debate by a great many people, many of whom have not had time to enter into the full details. I am surprised how often, after we

have made a decision, I get a telephone call within a few hours from somebody who wants to know the full background and all the reasons pro and con.

On the other hand, I think it is a good thing for people to learn what is involved in these developments in the way of the heartaches for the engineers, the failures of very minor devices, and so on. It is, of course, also good to share in the very great successes that we sometimes have.

SCHRIEVER: If we talk about secrecy and security in a general sense, certainly it can be very inhibiting. On the other hand, there are certain specific programs which can be accomplished only by the least possible number of people knowing about them.

CLARKE: You may not be aware of this, but the ECHO I satellite was one of the United States' space achievements that had the most impact on the world and gave this country international prestige. The reason for this prestige is a simple one. Everybody on Earth could see the ECHO I satellite with his own eyes under favorable conditions. In a sense, everyone viewing it was participating in the flight itself. They did not have to read about it, they could *see* it.

As many of you know, I am rather keen on communication satellites, having first thought of them in 1945. (In extenuation, I might add that I had never seen commercial TV then.) I would like to suggest that the United States has a chance to obtain a major "first" not only in prestige but also in technology and in every other respect. There is a magnificent opportunity to set up a global television network in time for the 1964 Olympics, with arrangements for a receiver and local network in every country. This would be fairly cheap, and I think its value in every respect would be enormous.

DRYDEN: We are very much aware of the many values to be obtained by early launching of communication satellites and early attainment of global capability. As you all know, we have only recently demonstrated live television across the Atlantic.

However, the communication satellite is something like jet transportation. It is a device for transmitting a program from one country to another country. But you must realize that the satellite is, in turn, dependent on each country's local stations and local home

receiving sets to have the program reach its audience. There are many countries that do not yet have television stations. I think the establishment of these local networks within countries that do not have them would be a fairly expensive proposition. We hope in the early work to have the cooperation of Great Britain, France, and Germany, and we hope to have at least one station in South America.

Everyone has been studying the possibility of transmission from a satellite to receivers in homes. One of the major problems we must solve is that the size of the antenna required to receive a satellite-beamed program and the sensitivity of the receiver set are not such as to be found in ordinary home receivers. But as our future payloads increase and as we develop nuclear sources of power for satellites, it may be that we can ultimately produce a successful system. In any event all of us are fully aware of the urgency of obtaining some global capacity as early as possible.

Schriever: I certainly agree with Dr. Dryden. I do not believe that we can accomplish the TV objective Mr. Clarke mentioned by 1964. But I believe a communication satellite does have tremendous prestige potential, not only in civilian life but from a military standpoint as well.

There is no question but that we have to develop satellite communication as rapidly as we can. The threat of nuclear attack by rocket has changed the time for decision from a matter of days or weeks to one of minutes. Our communication systems today are simply not appropriate to the demands that the world has placed upon the decision-making process. Much can be done along this line by the use of communication satellites, so they are of extreme importance not only with respect to prestige and with respect to civilian applications but also with respect to military applications.

Krieger: I don't believe the Soviet authorities would cooperate in any world-wide television system. In the Soviet Union the popular science literature has quite a few articles on communications satellites, but I think they are designed to suggest the possibility of such a system rather than actually to try to implement it.

Clarke: I should think the Soviet Union might well be frightened of the idea of satellite tv. All their public information must first be

screened by the censors. A working satellite TV broadcast network would certainly abolish many of their forms of censorship.

I would like to amplify somewhat the point that was mentioned just previously, that at this stage of our development, it will only be possible to transmit from satellites to rather sensitive ground receivers with large antennas. We are aware we cannot have satellite-to-home TV at this point, but home receivers can become our ultimate goal. In terms of the present, these satellites could be used for beaming programs to key areas all over the world. Enormous crowds would most certainly be attracted to these TV receivers, and these viewers would be seeing this magnificent technical achievement from the United States with their own eyes. It's another opportunity to have them participate on a personal level in one of our successes. It would have enormous popular appeal, particularly at the time of the 1964 Olympics, because this is something in which the whole world is interested.

Ultimately, I am sure, we will be able to pick up transmission directly in our homes. We will no doubt arrive at the time when we have space stations big enough to have very large antennas capable of beaming service to specific countries, and it obviously will be more economical to flood a country with television programs from satellites than to try to cover comparable territory from a multitude of ground transmitters.

I would like to terminate the discussion with a look into the future. In the past, countries have collapsed because they were too ambitious and over-reached themselves in trying to carve out empires. To imagine that a single nation can conquer space is pure megalomania. Sooner or later the sheer scale of space exploration is going to force international cooperation. What can be done to begin preparations for such cooperation now? When can we integrate the United States and the U.S.S.R. space programs?

DRYDEN: There is a tremendous international cooperative program going on right now in which the U.S.S.R. will not and does not participate. But a positive, united global effort with all other nations does exist. It is true that this is embryonic. It has taken time to get started. There is no clear formulation of a central group, and it will take time for these central groups, once organized, to find their proper roles in international cooperation. We find in many countries there are still debates going on between civilians and the military,

between electronics and rocket people, and so on. But these embryonic differences will be resolved in time, and nations will grow sufficiently to participate in true global cooperation.

One significant reason for a program of true international cooperation is the financial burden of space research which the United States has assumed. With more countries cooperating in the same research programs, the cost per United States citizen would be substantially lower.

I would like to recall the stories about the cost of Shepard's first suborbital flight. The story as reported was that it cost $2.25 for every citizen in the United States. However, this was the cost of the whole MERCURY Project, not of Shepard's flight. The cost of the whole MERCURY Project was $2.25 per person, and the cost of the Lunar Project is estimated at perhaps $50 to $100 per person, spread over some eight or nine years. This is not yet an excessive amount for either the United States or the U.S.S.R. But as we get more ambitious, the costs mount.

I agree that as soon as we find any disposition on the part of the U.S.S.R. to cooperate in space, this should be done. I have taken every opportunity to discuss cooperation with Professor Sedov and General Blagonravov and with others who have come to this country. Many other United States scientists have also attempted to discuss cooperation. We soon find that the Russians are not willing to go very far; they are not willing to discuss seriously anything beyond exchange of information or, perhaps, making a few observations on each others' satellites. We hope this situation will change.

It is a part of the whole climate of our relationship with the U.S.S.R. that as long as they are motivated, as they seem to be, by a sense of conflict it is going to be very difficult to cooperate in this field.

SCHRIEVER: I am not very optimistic on the matter of cooperation. First, the parties of the two parts must want to cooperate. I do not see anything in the make-up of communism that indicates that they want to cooperate.

With regard to the ability of a nation, particularly this country, to undertake and complete a major space program such as we have undertaken now, I believe that we can do it, that we will do it, and that we could do even more. We have resources that are definitely not being used at the present time. In this country today we have

some five or six million unemployed. In recent years our annual gross national product growth has been less than we would really like it to be. Some of our basic industries are operating at 50 per cent of capacity. I do not believe that there is any question about our ability to perform the space job we have before us.

I not only become annoyed, but I get extremely upset by those who take a defeatist attitude. I look back to the time when President Roosevelt said that we were going to build 50,000 airplanes a year and everyone insisted it could not be done. We not only did it, we built more. The space program is not nearly as massive as building 50,000 airplanes a year.

I do not agree with the thesis that this program is too big for any one nation to undertake. We can do it.

KRIEGER: As long as the Soviet Union follows its present philosophy of dialectical materialism, there will never be any cooperation on its part. It will have to be a one-sided affair.

KANTROWITZ: I think that any possibility of working out a cooperative program with the Russians awaits our success in earning their respect in the space business. We have to beat them a few times and beat them badly. We will have to beat them in ways they can recognize, such as the manned orbital flights in the full glare of world publicity. Cooperation may then be possible.

VON BRAUN: I also fail to see any possibility for direct cooperation from the Soviets in any technical area at this time. There is a military undertone to any kind of powerful rocket, in the simple fact that rockets obviously can be used as long-range weapons carriers.

On the other hand, I would imagine that once we have landed on the Moon and are building research stations there, and the Russians have landed in some nearby crater and are doing the same thing, the atmosphere will be very different. On the Moon there could be a kind of cooperation on the pattern of the present cooperation in Antarctica. This is entirely feasible where there are two independent national research stations. In case of trouble befalling one of the two stations, this could even lead to a degree of mutual help. I could imagine a situation of this type today in Antarctica. Should an American airplane have to make an emergency

landing somewhere on the snow wastes near a Russian camp, its crew could conceivably expect some help.

A similar situation of mutual help might also arise in orbit. After all, space has a certain similarity to the open seas. It is owned by nobody. Let us imagine that a United States satellite station happens to run into trouble and a Russian rocket chances to pass nearby. This represents a situation comparable to an emergency on the high seas. I can envision a certain degree of cooperation in such a case even if the political environment were not at all suitable for close technical cooperation.

Clarke: I also had the analogy of Antarctica in mind. Also, in my opinion, many people have failed to understand the vastness of space itself. In the solar system we have land areas roughly 250 times that of the planet Earth to explore in the next century or so. This is going to be a somewhat gigantic undertaking.

I would like to end this discussion by asking each of the panelists to give his view of the best single action that has been or could be taken to improve the United States' position in space.

Dryden: The most significant thing that has happened so far is the decision of President Kennedy to go ahead with the long-range objective of landing three men on the Moon. This decision is in itself a means of accelerating and integrating the development of space technology. His decision also has significant implications for our economy. To illustrate what this means: Jim Van Allen was asked not long ago how he expected anybody to make any money out of the Van Allen radiation belts. He said, "I am making a living out of them!" There are a lot of people who are going to make a living out of the billions in the NASA space budget this year.

Looking to the future, the most significant boost to our space program would be full public support of the increase in our budget that is going to be necessary next year. Unless that is done, much of the money that we got this year will be completely wasted, because it is barely the down payment on our very large undertakings in space.

Schriever: Space development holds a great potential for national security and even survival in the years ahead. I do not think that

this is clearly understood by the American people today, and I believe that no programs will ever get very far in this nation without the support of the people. We need to stress this need for national safety and survival until there is agreement on an effective international control with respect to the utilization of space for peaceful purposes. All the people of this country must clearly understand the reason for our space research. This public-information aspect of the space program, in my opinion, needs stressing and restressing.

KRIEGER: One of my heroes in history is Marshal Foch. Noted for his direct approach to a problem, his characteristic expression was "*Allons!*"

KANTROWITZ: As I stated earlier, the most desperate necessity for doing something about our program is to remove what I regard as the falsehood at its heart, that there is a distinction between civilian and military space.

VON BRAUN: We read a lot nowadays about the need for a crash program in outer space. I think it should also be clearly understood that a space program is a long-range proposition. As Dr. Dryden said, this year's budget is just the down payment for things to be built in the years to come. What we really need in this country is not a crash program but a sustained effort over a great number of years. We would be much happier with a little less of a crash program, but rather a program based on reliable public support of our space program for at least the next decade.

GLOSSARY OF SPACE TERMINOLOGY*

By The Editors

ABLATION Melting of nose cone materials during re-entry of spacecraft or other vehicles into the Earth's atmosphere at hypersonic speeds.

ABLESTAR (or ABLE) Upper-stage liquid propellant rocket engine system manufactured by the Aerojet-General Corporation. Often used with ATLAS or THOR boosters for many space missions.

ABORT Failure of an aerospace vehicle to accomplish its purposes for any reason other than enemy action. An abort may occur at any point from start of countdown for take-off to the destination.

ACCELERATION The rate of increase of velocity.

ACCELEROMETER A device which measures acceleration.

ACQUISITION The detection of a "target" satellite or space vehicle by some sensing device, which then permits a tracking device to "lock on" to the target and track it.

ACTUATOR A powered device which performs a mechanical movement; *e.g.*, "power steering" is performed by an actuator.

AERODYNAMICS That field of dynamics which treats of the motion of bodies relative to the air and the forces that act upon the bodies, especially as they relate to flight through the air.

AEROBEE A sounding rocket developed by Aerojet-General for scientific studies at altitudes of 100 to 200 miles.

AEROSPACE An operational indivisible medium consisting of the total expanse beyond the Earth s surface.

AEROSPACE PLANE A popular term for a high-speed airbreathing vehicle which can propel itself up to orbital speeds within the atmosphere.

AEROSPACE VEHICLE Specifically, an aerospace vehicle is one which functions both in the atmosphere and in the space equivalent or space environment. In its general sense, any vehicle, manned or unmanned, which operates in the aerospace environment.

AGENA Upper-stage liquid-propellant rocket engine system manufactured by Bell Aerosystems, Inc. Often used with ATLAS, THOR, or TITAN boosters for many space missions.

AIR BREATHER A missile or vehicle propelled by fuel oxidized by intake from the atmosphere.

AIR-LAUNCHED BALLISTIC MISSILE (ALBM) A ballistic missile which is carried aloft and launched from an aircraft.

AIRFOIL Any aerodynamic surface

* Parts of this Glossary are included by courtesy of the United States Air Force.

designed to obtain a reaction from the air through which it moves. An aileron, wing, rudder, or similar device is an airfoil.

AIRFRAME The assembled structural and aerodynamic components of an aircraft or missile which support the different systems and subsystems integral to the missile or aircraft.

AMBIENT Environmental conditions such as the pressure or temperature.

ANALOGUE COMPUTER A machine which solves problems by simulating mathematical operations and equations with mechanical and electrical devices.

ANGSTROM A unit of length, used extensively by spectroscopists, equal to one-hundred-millionth of a centimeter (10^{-8} centimeter).

ANGULAR MOMENTUM The linear momentum of an object which moves in a circle, multiplied by the radius of the circle. Angular momentum cannot be destroyed, just as momentum, energy, and mass cannot be destroyed.

ANTIGRAVITY An effect upon masses, such as rocket vehicles and human bodies, by which some still-to-be-discovered energy field would cancel or reduce gravitational attraction of Earth.

ANTIMISSILE MISSILE A defensive missile launched to intercept and destroy other missiles in flight.

ANTISATELLITE MISSILE A missile designed to destroy an orbiting satellite.

APHELION The point on a elliptical orbit around the Sun which is farthest from the Sun. (The Earth's aphelion is about 94,500,000 miles from the Sun.)

APOGEE The point or position at which a moon or an artificial satellite in its orbit is farthest from its primary.

APOLLO A name for the program whose goal is manned lunar landing and return by 1970.

ARCJET See PLASMA JET.

ASTEROID One of many thousands of minor planets which revolves around the Sun, between the orbits of Mars and Jupiter. All are very small compared with major planets. Ceres, the largest, is 480 miles in diameter; the majority are less than 50 miles; and some are about one mile in diameter.

ASTRONAUT One who flies or navigates through space.

ASTRONAUTICS The art or science of designing, building, or operating space vehicles.

ASTRONOMICAL UNIT A unit of measure of distances within the solar system. It is equal to one mean diameter of the Earth's orbit around the Sun.

ASTROPHYSICS The physics of phenomena occurring outside the Earth's atmosphere.

ATLAS (SM-65) An Air Force strategic bombardment missile whose range is 5,500 nautical miles. America's first intercontinental ballistic missile, ATLAS, had its first successful flight in August, 1958. ATLAS is the prime propulsion unit or booster for many research projects.

ATMOSPHERE The envelope of gases that surrounds a celestial body.

ATOMIC HYDROGEN Hydrogen gas in which the normal hydrogen molecules consisting of two atoms have been torn apart into their constituent atoms.

ATTITUDE-CONTROL JETS Sometimes called steering jets, attitude jets, or roll, pitch and yaw jets:

fixed or movable gas nozzles on a rocket missile or satellite, operated continually or intermittently to change the attitude or position in aerospace.

AURORA Commonly known as the Northern and Southern lights. A high-altitude airglow caused by solar particles, predominantly protons, moving as charged particles in the Earth's magnetic field and interacting with the Earth's' atmosphere.

BALLISTIC MISSILE Any missile that does not rely on aerodynamic surfaces for lift and utilizes reaction propulsion as a power source. Such a missile, normally guided by external or internal means during the first portion of its flight, follows a ballistic trajectory determined by gravational and atmosphere drag forces after launch power is cut-off.

BALLISTIC MISSILE EARLY WARNING SYSTEM (BMEWS) An electronic system to provide detection and early warning of attack by enemy intercontinental ballistic missiles. The system will have long-range radar bases to provide prompt warning of missile attack across the polar region, supplementing the present Distant Early Warning (DEW) Line built across the top of the continent to warn against bomber attack. Three BMEWS stations are presently involved—one at Thule, Greenland; one at Clear, Alaska; and one in the British Isles.

BALLISTIC MISSILE INTERCEPTOR An interceptor, specifically, an explosive rocket missile, designed to home upon and destroy a ballistic missile in flight. This term is sometimes used as a synonym for "antimissile missile."

BLACK BOX A term used loosely to refer to any component, usually electronic, which can readily be inserted or removed from a specific place in a larger system without knowledge of its detailed internal structure.

BLIP A spot of light or other indicator on a radarscope indicating the relative position of a reflecting object, such as a missile in flight.

BLOCKHOUSE The reinforced building used by launch personnel. It also houses the equipment needed for checkout and launch.

BOMARC (IM-99) An Air Force surface-to-air guided missile with a range of 200-400 miles. Bomarc is an area defense interceptor missile, powered by twin ramjet engines with either liquid or solid rocket booster.

BOOST-GLIDE VEHICLE A vehicle that is boosted into orbit by rocket engines, and then utilizes aerodynamic surfaces to glide to any preselected point on Earth.

BOOSTER ROCKET A rocket motor that assists the normal propulsive system of a rocket or other aerospace vehicle in some phase of its trajectory or flight path. Also applied to a first-stage rocket.

BRAKING ELLIPSES A series of orbital approaches to the Earth's or any other planet's atmosphere for the purpose of slowing up a rocket preparatory to landing.

BURNOUT The point in time or in the missile trajectory when propellant is exhausted or its flow is cut off, resulting in termination of thrust.

CAPE CANAVERAL A cape on the east coast of Florida used as a laboratory for launching missiles or space vehicles. The Air Force Missile Test Center operates the launching site, officially known as the Atlantic Missile Range.

CAPSULE A small, sealed, pressurized cabin with an acceptable environment, usually for containing a man or animal for extremely high-altitude flights, orbital space flight, or emergency escape.

CAPTIVE OR STATIC FIRING A test firing of a complete missile in which all or any part of the propulsion system is operated at full or partial thrust while the missile is restrained in the test stand.

CAVITATION The rapid formation and collapse of vapor pockets in a flowing liquid under very low pressures—a frequent cause of serious structural damage to rocket components.

CELESTIAL GUIDANCE The guidance of a missile or other vehicle by reference to celestial bodies. (The missile is equipped with telescopes, mechanically or electrically recorded navigational tables, computers, and other instruments and devices that sight stars, calculate position, and direct the missile.)

CENTAUR A high-energy upper stage to provide a 4- to 5-ton orbital payload capability when used as a second stage to an ICBM booster, such as the Air Force ATLAS.

CENTRIFUGAL FORCE A force that is directed away from the center of rotation.

CHEMICAL FUEL A fuel that depends upon an oxidizer for combustion or for development of thrust, such as liquid or solid rocket fuel, jet fuel, or internal-combustion-engine fuel. Distinguished from nuclear fuel.

CIRCUMLUNAR Trips or missions in which a vehicle will circle the Moon and return to Earth.

CISLUNAR SPACE The neighborhood of the moon, generally taken as the region beyond the sphere of activity of the Earth's gravitational field.

CLOSED ECOLOGICAL SYSTEM A system that provides for the body's metabolism in a spacecraft cabin by means of a cycle wherein exhaled carbon dioxide, urine, and other waste matter are converted into oxygen and food.

CLUSTER Two or more engines bound together so as to function as one propulsive unit.

COMET A loose body of gases and solid matter revolving around the Sun.

CORE The heart of the nuclear fission reactor in a nuclear rocket or nuclear-electric power supply. The core generally is considered as the part of the reactor which contains the fissionable fuel.

CORPORAL An early liquid-propellant tactical missile.

COSMIC RAYS Extremely fast particles continually entering the upper atmosphere from interstellar space. They are atomic nuclei which have very great energies because of their enormous velocities and are potentially dangerous to life experiencing extended exposure.

COSMONAUT The Soviet term for Astronaut.

COUNTDOWN The step-by-step process leading to missile launching. It is performed in accordance with a predesignated time schedule, measured in terms of T-Time (T minus time prior to initiation

of engine start sequence and T plus time thereafter).

COURIER Project name for a 1960 satellite communications experiment.

CRITICALITY The condition at which a nuclear reactor can sustain the fission reaction by itself. This requires a certain minimum mass of fissionable fuel, called the "critical" mass.

CRYOGENICS The technology of very low-temperature liquids; *e.g.*, liquid oxygen, liquid hydrogen, and liquid helium.

CUT-OFF The shutting off of the liquid- or solid-propellant combustion process of a rocket engine, thereby causing a rapid drop toward zero thrust.

DATA REDUCTION The action or process of reducing data to usable form, usually by means of electronic computers and other electronic equipment.

DC-6 One of the large propeller-driven commercial aircraft built in the United States and still in use by airlines all over the world.

DECELERATION Negative acceleration (slowing down).

DE-ORBIT The operation of braking a satellite or space vehicle out of orbit. This is always the first step in any Earth, lunar, or planetary landing from orbit.

DESTRUCT The deliberate action of detonating or otherwise destroying a rocket missile or other vehicle after it has been launched but before it has completed its course.

DETONATION An extremely rapid reaction in which an oxidizer and a fuel combine with large evolution of heat.

DEW LINE (DISTANT EARLY WARNING) A defensive line of radar stations at about the 70th parallel on the North American continent, provided NORAD by the U.S. Air Force.

DIGITAL COMPUTER A computer in which quantities are represented numerically and which can be used to solve complex problems relating to missile flights and operations.

DISCOVERER An Air Force research program for the development of advanced space vehicles and systems to perform sophisticated tasks in space. Biomedical specimens are carried by some of the vehicles in the DISCOVERER series to investigate reaction to the space environment.

DISSOCIATION Tearing apart the atoms which make up a molecule. This occurs when the molecules are heated to high temperatures. The opposite process, "recombination," occurs when the hot, dissociated atoms are cooled down.

DOCKING The operation following rendezvous, in which two space vehicles are brought into contact and locked into place.

DOD Department of Defense.

DOPPLER EFFECT The apparent change in frequency of vibrations, as of sound, light, or radar, when the observed and observer are in motion relative to one another.

DOSE The total quantity of high-energy radiation absorbed over a period of time. Excessive "doses" of gamma, neutron, or high-energy proton radiation can cause severe illness or death.

DOWNRANGE In a direction away from the launch site and along the line of a missile test range.

DRAG The aerodynamic force in a

direction opposite to that of flight and due to the resistance of the body to motion in air.

DRIFT ERROR A change in the output of an instrument over a period of time. It is usually caused by random wander or by conditions of the environment.

DRONE An unmanned, self-propelled air vehicle, remotely controlled and specifically designed to be used for reconnaissance, as a target, or for other non-destructive purposes.

DRY WEIGHT The weight of a rocket vehicle without its propellants.

DYNA-SOAR This is the USAF follow-on program to the X-15 program. Final objective: using boost-glide principle, vehicle is to be launched in midair, skip in and out of the atmosphere to slow itself, and finally glide home with the pilot using aerodynamic controls.

EARTH SATELLITE A body that orbits about the Earth; specifically such body placed in orbit by man, otherwise called "artificial Earth satellite."

ECHO A series of "passive" communications satellites, consisting of large metallic balloons which can reflect radar or radio signals.

ECLIPTIC The plane of the Earth's orbit around the Sun. It is used as a reference for other interplanetary orbits.

ESCAPE VELOCITY The speed a body must attain to overcome a gravitational field, such as that of Earth, and thus theoretically travel on to infinity. The velocity of escape at the Earth's surface is 36,700 feet per second. A practical manned spacecraft would travel the atmosphere at a lower velocity and accelerate to escape velocity beyond in order to avoid drag, unacceptably rapid initial acceleration, and high skin temperature from aerodynamic heating.

EXHAUST VELOCITY The speed at which the jet of gases of a rocket or jet engine leaves the engine, relative to the engine. The "effective" exhaust velocity is directly proportional to the "specific impulse" and thus is a measure of engine performance.

EXOSPHERE The outermost fringe or layer of the atmosphere, where collisions between molecular particles are so rare that only the force of gravity will return escaping molecules to the upper atmosphere.

EXOTIC FUEL The unusual fuel combinations for aircraft and rocket use with the purpose of attaining greater thrust.

EXPLORER A series of small, very simple satellites used for space science experiments. EXPLORER I was the first successful U.S. satellite.

EXTRATERRESTRIAL Relating to other than the planet Earth.

F-1 A 1½ million-pound liquid-propellant rocket engine developed by Rocketdyne using liquid oxygen and hydrocarbon fuel.

FISSION The splitting of an atom resulting in the production of nuclear energy. This is the energy utilized in the nuclear rocket, the nuclear-electric generating system, and the "atomic" bomb.

FISSIONABLE FUEL The elements which can be used to power a nuclear fission reactor (uranium-235 or plutonium).

FLAME DEFLECTOR The steel or

concrete surface, usually water-cooled, on which a booster's rocket engine exhaust flame impinges during static tests or launch operations.

FLUX Rate of flow, usually in particles or intensity per unit area per unit time.

FOLLOW-ON Any object, group of objects, technique, or procedure considered to be a second or subsequent generation in development.

FREE GYRO Sometimes referred to as "space reference gyro," in that the free gyro will maintain its orientation with respect to the stars rather than with respect to the Earth. Its inability to maintain this space reference is a measure of its inherent inaccuracy.

FUSION The combining (fusing) of atoms to release energy. This is the form of energy used in the "hydrogen" or "thermonuclear" bomb. Its control for power or propulsion applications has not yet been achieved.

G OR G-FORCE Force exerted upon an object by gravity or by reaction to acceleration or deceleration, as in a change of direction; one G is the measure of the gravitational pull at sea level on the Earth.

GALAXY (1) The group of several billion suns, stars, star clusters, nebulae, etc. to which the Earth's Sun belongs. Also called the Milky Way. The Galaxy is generally considered by astronomers to be shaped like a great disk of stars irregularly dispersed in clusters. Its diameter is 30,000 parsecs, its thickness 1,000 to 2,000 parsecs except at the center where it is 5,000 parsecs or more. (2) Any of several similar groups of stars forming isolated units in the universe.

GAMMA RAY A form of very high-energy electromagnetic radiation. Gamma rays always appear as the by-product of nuclear reactions and other reactions resulting from high-energy particle interactions.

GANTRY Crane-type structure, with platforms on different levels, used to erect, assemble, and service large missiles; may be placed directly over the launching site and rolled away just before firing.

GENERATION In any technical or technological development, as of a missile, jet engine, or the like, a stage or period that is marked by features or performances considered to be primitive, sophisticated, maturing, or matured, as in "the first generation of rockets used liquid propellants."

GENIE An Air Force air-to-air rocket equipped with nuclear warhead, which was first fired from an aircraft in mid-1957.

GEOCENTRIC Relating to or measured from the center of the Earth; having, or relating to the Earth as a center.

GEOCORONA Outer atmospheric shell of the Earth, composed principally of hydrogen.

GEOMAGNETIC FIELD The magnetic field of the Earth.

GIMBAL A mechanical frame containing two mutually perpendicular intersecting axes of rotation (bearing and/or shafts).

GRAIN The solid propellant in a rocket engine. The "grain" is shaped so as to provide the desired burning characteristics.

GUIDANCE SYSTEM The aggregate of sensing, computing, and control devices needed to maintain

a space vehicle or booster on its preselected or desired course.

GUIDED MISSILE An unmanned vehicle, moving in aerospace, whose trajectory or flight path is capable of being altered by an external or internal mechanism.

GYROSCOPE Device consisting of a wheel so mounted that its spinning axis is free to rotate about either of two other axes perpendicular to itself and to each other; once set in rotation, its axle will maintain a constant direction even when the Earth is turning under it.

H-1 A liquid-propellant rocket engine in the 150,000-200,000 pound thrust class, used on ATLAS, THOR, and SATURN C-1 boosters.

HARDWARE The physical object, as distinguished from its capability or function. The actual engines, case, pumps, guidance system, or other components of the missile.

HELIOCENTRIC Relating to the Sun as center.

HOME (1) Of a guided missile: to direct itself towards a target by guiding on heat waves, radar, echoes, radio waves, or other radiation emanating from the target. (2) To cause a missile to go towards an object emitting radiation.

HOUND DOG (GAM-77) An Air Force air-to-surface guided missile with a range of over 500 miles.

HYDROMAGNETIC ACCELERATOR A device which accelerates plasmas, for use in space propulsion (see MAGNETO-HYDRODYNAMICS).

HYPERSONIC Extremely high velocities in gases. Hypersonic flight is generally considered as faster than Mach number 5 (5 times the local speed of sound).

INERTIAL FORCE The force produced by the reaction of a body to an accelerating force, equal in magnitude and opposite in direction to the accelerating force. Inertial force endures only so long as the accelerating force endures.

INERTIAL GUIDANCE An automatic spacecraft navigation system using gyroscopic devices. The system absorbs and interprets such data as speed, position, etc., and automatically adjusts the vehicle to a predetermined flight path.

INERTIAL SPACE A frame of reference that is fixed with respect to the stars.

INFRA-RED GUIDANCE A system for reconnaissance of targets and navigation using infra-red heat sources.

INTERCEPTOR MISSILE A missile designed to counter enemy offensive forces.

INTERCONTINENTAL BALLISTIC MISSILE (ICBM) A ballistic missile with sufficient range to strike at strategic targets from one continent to another. The ICBM minimum range is approximately 5,000 miles. The ATLAS, TITAN, and MINUTEMAN are designated as ICBM's.

INTERGALACTIC SPACE That part of space conceived as having its lower limit at the upper limit of interstellar space, and extending to the limits of space.

INTERMEDIATE RANGE BALLISTIC MISSILE (IRBM) A ballistic missile with a range above 200 miles but less than 1,500 miles. (The limitation of range as shown

is subject to change as new concepts of weapons employment are entertained.)

INTERNATIONAL GEOPHYSICAL YEAR (IGY) An international cooperative program to study the Earth and its environs. Our first satellite program VANGUARD, was initiated in order to supplement IGY data.

INTERPLANETARY SPACE That part of space conceived, from the standpoint of the Earth, to have its lower limit at the upper limit of translunar space, and extending to beyond the limits of the solar system some several billion miles.

INTERSTELLAR FLIGHT Flight between stars, strictly between orbits around the stars. The shortest interstellar flight from the solar system is to Proxima Centauri, a distance of 24×10^{12} miles. Traveling at the speed of light, an interstellar spacecraft would take 4½ years for such a journey, and a similar time for the return.

ION An electrically charged atom or group of atoms. (A positively charged ion is an atom or group of atoms with a deficiency of electrons; a negatively charged ion is an atom or group of atoms with an added electron.)

ION ENGINE A type of engine in which the thrust to propel the missile or spacecraft is obtained from a stream of ionized atomic particles.

IONOSPHERE An outer belt of the Earth's atmosphere in which radiations from the Sun ionize, or excite electrically, the atoms and molecules of the atmospheric gases. The height of the ionosphere varies with the time of day and the season, but its lower limit is generally considered to lie between twenty-five and fifty miles.

J-2 A liquid-propellant rocket engine using liquid hydrogen and liquid oxygen to produce 200,000 pounds of thrust. It is under development by Rocketdyne.

JATO A small, unitized rocket engine, usually solid-propellant, used for Jet Assisted Take-Off of aircraft.

JET AIRCRAFT A vehicle which breathes air and is propelled by the thrust of exhaust gases.

JET ENGINE A reaction engine that takes in air from ouside as an oxidizer to burn fuel and ejects a jet of hot gases backward to create thrust, the gases being generated by the combusion within the engine. The jet engine differs from the rocket engine in its dependence upon air taken in from outside. The rocket engine carries its own oxidizer and is therefore capable of operation in outer space.

JETEVATOR A control surface that may be moved into or against a rocket's jet stream and used to change the direction of the jet flow for thrust vector control.

JUPITER (SM-78) An Air Force intermediate range ballistic missile with a range of 1,500 nautical miles.

KELVIN SCALE (°K) named after the first Baron Kelvin (1824-1904), an English mathematical physicist and inventor. A temperature scale that uses centigrade degrees but makes the zero degree signify absolute zero. (Water freezes at 273.16°K and boils at 373.16°K.)

KILO a prefix denoting 1,000; *e.g.*, kilowatt, kilometer, etc.

KIWI Nuclear rocket research and feasibility-test reactors. The KIWIS are not intended for flight testing.

LANDING ROCKET A space vehicle operated to transfer passengers or cargo from a satellite or larger orbiting spacecraft to the surface of a planet. A landing rocket must be provided with means of reducing its velocity for a safe entry into the planet's atmosphere and the touchdown.

LAUNCH A name for the operation during which a space vehicle booster or ballistic missile takes off from the earth.

LAUNCH COMPLEX The entire system of buildings, services, and installations required to launch large boosters.

LAUNCH PAD A concrete or other hard surface area on which a missile launcher is positioned.

LAUNCHER A structural device designed to physically support and hold a missile in position for firing. It does not include checkout and service equipment necessary to launch a missile.

LIFE-SUPPORT SYSTEM The equipment and supplies needed to maintain man in space. This includes food, water, air supply, heating or conditioning, waste removal, etc.

LIFT-OFF The initial motion along the trajectory of a space vehicle or ballistic missile as it rises from the launch stand under rocket propulsion; the take-off.

LIGHT-YEAR The distance traveled in one year by light which covers 186,284 miles in one second. One light-year is equal to 5,880,000,000,000 miles.

LIQUID PROPELLANT Any liquid ingredient fed to the combustion chamber of a rocket engine.

LITTLE JOE An inexpensive solid-propellant booster used for early unmanned flight tests of the MERCURY capsules.

LOGISTICS The entire operation of providing all supplies necessary for a mission or class of missions.

LUNAR BASE A projected installation on the surface of the Moon for use as a base in scientific or military operations.

LUNAR GRAVITY The attraction of particles and masses towards the gravitational center of the Moon.

LUNAR PROBE A probe for exploring and reporting on conditions on or about the Moon.

LUNAR SPACE The space near the Moon. (The gravitational attraction of the Moon is predominant in lunar space.)

LUNIK Project name for the Soviet moon probes.

LYMAN-ALPHA LINE One of the ultraviolet wave lengths emitted from excited hydrogen atoms.

M-1 A liquid-propellant rocket engine providing 1.2 million pounds of thrust, using liquid hydrogen and liquid oxygen. It is under development by the Aerojet-General Corporation.

MACE (TM-76A) An Air Force surface-to-surface guided missile with highly sophisticated guidance system and a range of over 600 miles. The MACE is an improved version of the MATADOR, but sufficiently changed so as to warrant its classification as an entirely new missile. The MACE was first launched in early 1959.

MAGNETO-HYDRODYNAMICS The science of fluid mechanics of an electrically-conducting gas, and the effects of magnetic and electric fields on the gas.

MAGNITUDE The brightness of a star. First magnitude is the brightness of a candle flame at a distance of 1,300 feet.

MAIN STAGE (1) In a single-stage rocket vehicle powered by one or more engines, the period when full thrust (at or above 90%) is attained. (2) In a multi-stage rocket, the stage that develops the greatest amount of thrust, with or without boosters. (3) A "sustainer" engine, considered as a stage after booster engines have fallen away.

MAP-MATCHING GUIDANCE (1) The guidance of a missile or flight-borne vehicle by means of a radarscope film previously obtained by a reconnaissance flight over the terrain of the route and used to direct the missile or other vehicle by aligning itself with radar echoes received during flight from the terrain below. (2) Guidance by stellar map-matching.

MARINER A series of unmanned spacecraft scheduled for fly-by and hard-landing explorations of Mars and Venus.

MASS RATIO Fraction of a vehicle's mass which consists of propellant. The mass ratio is also often expressed as the initial vehicle mass divided by the final vehicle mass (after the propellant has been expended) or the inverse; *i.e.*, final mass divided by initial mass.

MATADOR (TM-61) An Air Force surface-to-surface guided missile that has a range of several hundred miles. This was the Air Force's first operational missile, and made its first flight in 1950.

MERCURY The manned orbital (up to 150 miles out) flight training program for seven military test pilots, under direction of NASA, with aeromedical support by the Air Force and the Navy.

METEOR BUMPER A thin shield, comparable in thickness with the diameter of the meteor to be intercepted, around a space vehicle and designed to thermally dissipate the energy of meteoritic particles. High impact velocity of the meteor leads to vaporization of the meteor and a part of the shield without penetration of any particles to the wall of the space vehicle.

MICROWAVES Electromagnetic radiation in the radar range, but at very short wave lengths. Useful for television and line-of-sight radio communication.

MIDAS A project initiated to develop an early warning system against ballistic missile attacks, based on the use of satellites.

MIDCOURSE CORRECTION A spacecraft maneuver needed to correct course errors resulting from initial inaccuracies in propulsion-system thrust level or direction.

MINUTEMAN (SM-80) An Air Force intercontinental ballistic missile that has a designed range of 5,500 nautical miles, powered by three stage solid-propellant rocket engines. Lighter, smaller, and simpler than the liquid-fueled ICBMs, the MINUTEMAN may be stored in hidden underground bomb-proof silos ready to be fired on a moment's notice, or deployed on railway cars and trucks and kept constantly on the move from place to place.

MISSION The purpose of a space project.

MODULE A combination of components, contained in one package or so arranged that together they are common to one mounting, which provide a complete function or functions to the subsystems and/or systems in which they operate.

MOLECULAR WEIGHT The relative weight of the molecules of a chemical element or compound, based on a scale in which the oxygen atom has a "molecular weight" of 16, the hydrogen atom approximately 1.

MONOPROPELLANT A rocket propellant in which the fuel and oxidizer are premixed or form a single chemical compound.

MOON ROCKET A rocket vehicle used to carry a payload to the Moon, either to circle it and return to Earth or to land upon it.

MULTISTAGE VEHICLE Two or more component vehicles which operate in series in order to increase the attainable payload velocity. The first stage is usually called the booster.

NASA National Aeronautics and Space Administration.

NEBULAE Galactic nebulae are clouds of interstellar matter which are revealed either because they are illuminated by a bright star or because they noticeably weaken the light from stars in a particular region of the sky.

NERVA (Nuclear Engine for Rocket Vehicle Applications.) The program for flight-testing a nuclear rocket engine.

NEUTRON An electrically neutral particle which is one of the fundamental particles making up atoms.

NOSE CONE The shell that fits over, or is, the nose of an aerospace vehicle. It is built to withstand the high temperatures generated by friction with air particles.

NOVA A star which undergoes a sudden and enormous increase in brightness; about twenty-five appear every year in our galaxy. Supernova is a star which explodes with a liberation of most of its energy into space. NOVA is also used as project name for a series of very large liquid-propellant rockets beyond the Advanced SATURN class.

NOZZLE The exhaust duct of a rocket or a jet engine. It is shaped so as to convert the maximum possible amount of heat energy into thrust.

NUCLEAR FUEL A fuel used in a nuclear reactor; usually uranium-235 or plutonium.

NUCLEAR PROPULSION Propulsion by means of nuclear energy. Nuclear propulsion may be applied to either airbreathing jet engines or to rockets. Rockets that utilize a nuclear reactor to heat their propellant directly are called "nuclear heat-exchanger rockets" or simply "nuclear rockets."

NUCLEAR-ELECTRIC PROPULSION A spacecraft propulsion system using an electric engine (ion, arcjet, or hydromagnetic) supplied by an electric power plant utilizing a nuclear reactor as its prime energy source.

ONBOARD GUIDANCE SYSTEM Also known as the airborne guidance system and the inflight guidance system. The automatic system on missiles and unmanned spacecraft that sends steering signals through the flight-control system

during the terminal phase of propelled flight.

ORBIT The path described by a celestial body or spacecraft in its revolutions around another body.

ORION Project name for a pulse-type nuclear propulsion system that uses the energy from small nuclear explosions.

OXIDANT An oxidizer. In a rocket propellant a substance such as liquid oxygen, nitric acid, or the like that yields oxygen for burning the fuel.

PAD A permanent or semipermanent load-bearing surface constructed or designed as a base upon which a launcher can be placed. Short for launch pad.

PARAGLIDER A combination parachute and wing considered for use as an aid to re-entering the Earth's atmosphere. Also called Parawing, Rogallo wing, or Rogallo kite.

PARSEC A unit of measure for instellar space equal to 3.26 light years.

PAYLOAD The useful part of a vehicle system; *i.e.*, that part of the vehicle which the rest of the vehicle is designed to carry.

PERIHELION The point on an elliptical orbit around the Sun which is nearest to the Sun. (The Earth's perihelion is about 91,500,000 miles from the Sun.)

PERSHING An all-solid ballistic missile used for tactical support by the Army.

PHOTON One of the minute particles which form streams to become light rays. These streams theoretically may be harnessed to power a spacecraft.

PHOTON ENGINE A projected species of reaction engine in which thrust is to be obtained from a stream of light rays. (Although the thrust of this engine is considered to be minute, it can be indefinitely applied to build up speeds approaching the speed of light, 186,000 mps.)

PHOTOSPHERE The outermost luminous layer of the Sun's gaseous body.

PICKET SHIP One of the ocean-going ships used on a missile range to provide added instrumentation for tracking or recovering the missiles. The picket ship may be used to extend the length of the range.

PILOTLESS AIRCRAFT An aircraft, such as a drone, unattended by a human pilot within it, but kept on course by a preset or self-reacting device or by radio command.

PIONEER Project name for a series of space probes sent on escape trajectories, some aimed toward the Moon.

PIPER CUB A small private airplane capable of carrying only two people.

PLASMA A gas which is fully or partly ionized.

PLASMA JET The former name for high-temperature jet of electrons and positive ions that has been heated and ionized by a strong electrical discharge. Now called an arcjet.

PLASMA THERMOCOUPLE or PLASMA DIODE A device which can convert heat directly into electricity.

PLUTO An Air Force project to develop nuclear-powered ram-jet engines.

POLARIS A Navy surface-to-surface sea-based intermediate range strategic bombardment missile that has a range of 1,500 miles. The POLARIS

is designed primarily for launching from fleet ballistic missile submarines.

PRESSURIZED CAPSULE A capsule that has within it a gaseous pressure (as that of air) greater than the ambient pressure.

PRESSURIZED SUIT A garment designed to provide pressure upon the body so that respiratory and circulatory functions may continue normally, or nearly so, under low-pressure conditions such as occur at high altitudes or in space, without benefit of a pressurized cabin.

PROBE A device used to explore, examine, and test the nature of something, especially a test sphere, Earth satellite, or other instrumented vehicle used to penetrate outer space and made to report back information on conditions encountered. Specifically, a probe is an instrumented vehicle that moves close to, around, or upon a spatial body, and reports back to the Earth by telemetry or by other means.

PROGRAM (1) To put into an electronic guidance unit or other electronic sequencer a particular event or action, as in "to program a roll." (2) To set a sequence of operations into an electronic sequencer. (3) To provide for a series of events during a flight or other action, as in "to program the flight for an early thrust cut-off."

PROJECTILE A body which is accelerated to a velocity by the application of mechanical forces and which continues its motion along a ballistic trajectory.

PROPELLANT (1) The oxidant and fuel burned and expanded to obtain propulsion or thrust. It may be either in liquid or solid form. (2) Also applied singly to any one of the ingredients of a liquid-propellant, *i.e.*, to the fuel, the oxidizer or to an additive.

PROPULSION SYSTEM A major system of a missile or other vehicle that includes the engines, booster tanks, and all necessary associated equipment to insure desired ground and in-flight engine operation.

PROSPECTOR A series of unmanned spacecraft originally scheduled for robot exploration of the moon. This project has since been included as part of APOLLO.

PROTOTYPE A model (of an airplane, guided missile, or other equipment) that is suitable for complete evaluation of form, design, and performance. A prototype model utilizes approved parts and is representative of the final equipment. It follows an experimental model and precedes the production model.

PULSEJET A jet-propulsion engine, containing neither compressor nor turbine, which produces thrust intermittently. It is equipped with vanes in the front end which open and shut.

RADIO TELESCOPE A radio receiving station for detecting radio waves emitted by celestial bodies or by space probes in space.

RAMJET A ramjet engine. A kind of jet engine consisting essentially of a tube open at both ends in which fuel is burned continually to create a jet thrust. The ramjet has neither compressor nor turbine, the air necessary for oxidizing the fuel being taken in and compressed, or "rammed in," by the high velocity of the engine as it moves.

RANGE The distance traveled by a rocket vehicle or airplane, usually used in reference to ground-miles covered over the Earth's surface.

RANGER A series of spacecraft used for lunar exploration. They are boosted by an ATLAS-AGENA and are designed for hard landings (falling) on the moon.

RATO (ROCKET ASSISTED TAKE-OFF) (1) A take-off assist by a booster rocket unit (see JATO). (2) The power unit used in such a take-off.

REACTION ENGINE An engine or motor that derives thrust by expelling a stream of moving particles to the rear. (The engine works in accordance with the third law of motion, *i.e.*, every action produces an equal and opposite reaction.)

RECOVERY The act of retrieving a launched missile or satellite that has survived re-entry.

REDSTONE An Army surface-to-surface ballistic missile JUPITER A) that has a range of 200 miles. REDSTONE is the outgrowth of the V-2, on which the Germans began working in 1940.

REDUNDANCY The use of several reserve systems or components in case of failure of the first one.

RE-ENTRY NOSE CONE A nose cone designed especially for re-entry, consisting of one or more chambers protected by an outer shield.

RE-ENTRY VEHICLE A spacecraft or missile subsystem that was originally called the "nose cone." It normally is understood to include a heat shield, a payload, a re-entry attitude control system when necessary, and some device for separation of the re-entry vehicle from the main vehicle structure.

RELATIVISTIC VELOCITY Speed approaching that of light, at which noticeable changes in mass, dimensions, and time scales are likely to appear.

RENDEZVOUS (1) the event of two or more aerospace vehicles meeting in flight at a preconceived time and place. (2) The point in aerospace at which such an event takes place, or is to take place.

REPEATER A retransmission or "active relay" device for communications signals.

RETROROCKET A rocket that gives thrust in a direction opposite to the direction of an object's motion, used to slow down the speed of the object or to separate a fall-away section or companion body from the remaining body.

RIFT (Reactor In Flight Test.) A program for nuclear rocket vehicle flight test.

ROCKET A thrust-producing system which derives its thrust from ejection of hot gases generated from material carried in the system, not requiring intake of air or water.

ROCKET ENGINE A rocket propulsive device that is relatively complicated in its workings, as distinguished from a rocket "motor." The liquid-propellant engine with its elaborate pumping equipment, pressure chambers, fuel lines, electrical connections, etc., is more appropriately called an "engine" than the solid-fuel "motor."

ROGALLO WING See PARAGLIDER.

ROVER The nuclear rocket research and experimental feasibility program, under cognizance of the Atomic Energy Commission.

SATELLITE An attendant body that

revolves about another body. Also a man-made object designed or expected to be launched as a satellite.

SATURN SATURN C-1 designates a space booster consisting of a cluster of eight ballistic missile type liquid-propellant rocket engines with a total thrust capability of about 1,500,000 pounds. The Advanced SATURN C-5 uses a cluster of five F-1 engines having a total thrust of 7,500,000 pounds.

SCORE Project name for the first communications satellite experiment in 1959.

SEEKER A guidance system which homes on energy emanating or reflected from a target or station.

SEISMOMETER or SEISMOGRAPH An instrument that measures the magnitude and shape of a vibration or shock wave, usually in solid materials. The most common use of seismic instruments is in the analysis of earthquakes.

SENSOR or SENSING ELEMENT A device that "senses" a measurement; *e.g.*, velocity, distance, etc.

SERGEANT An all-solid tactical missile used for close tactical support by the Army.

SERVO A device that produces an output (usually a position or speed of a shaft) which varies in a predetermined way with its input. Servos are the link between sensors or computers and actuators.

SHIELD Material needed to protect men or sensitive equipment against radiation. This can be either the natural radiation encountered in space or the radiation from a nuclear powerplant or rocket.

SIDEREAL A measurement of time. A sidereal day, for example, is the time it takes the Earth to make a complete revolution measured from the stars. A sidereal day is four minutes shorter than our day (which is called a solar day).

SIDEWINDER (GAR-8) A navy air-to-air missile, also used by the Air Force, designed to destroy high performance enemy fighters and bombers. It seeks the target by homing on the heat emitted from the target aircraft.

SILO A missile shelter that consists of a hardened vertical hole in the ground with facilities either for lifting the missile to a launch position or for direct launch from the shelter.

SOFT LANDING A landing on the Moon or other spatial body at such slow speed as to avoid a crash or destruction of the landing vehicle. Soft landings on the Moon are anticipated by use of retro-rockets for slow-down of the landing vehicle; soft landing on Mars may be accomplished by partial use of the Martian atmosphere.

SOLAR CORONA The outer atmosphere shell of the Sun.

SOLAR FLARE An occasional burst of high-energy particles from the Sun. Usually accompanies excessive sunspot activity. These particles constitute a serious radiation hazard to space crews.

SOLAR SPECTRUM All the electromagnetic radiation (including light) emitted from the Sun.

SOLAR WIND The flow of electrically-charged particles (solar plasma) from the Sun.

SOLID PROPELLANT A rocket propellant in solid state consisting of all the ingredients necessary for sustained chemical combustion.

SONIC BOOM An explosion-like sound heard when a shock wave,

generated by an aircraft flying at supersonic speed, reaches the ear.

SONIC SPEED The speed of sound. When an object travels in air or other medium at the same speed as that of sound in the same medium, it has reached sonic speed.

SOUNDING ROCKET A comparatively simple research rocket vehicle used to obtain data on the upper atmosphere and near-space region.

SPACE See AEROSPACE.

SPACE AGE An historical age in which man has achieved, in some degree, power to project missiles or vehicles into space.

SPACE ENVIRONMENT The environment encountered by vehicles and living creatures upon entry into space.

SPACE PLATFORM A large satellite with both scientific and military applications, conceived as a habitable base in space. The proposed space platforms would contain such things as housing facilities, power supplies, gravity simulation, provisions for transferring personnel and cargo to and from other space vehicles, scientific instruments, weapons systems, controlled atmosphere, and communication systems.

SPACE PROBE An instrumented vehicle, as a test sphere or Earth satellite, that is rocketed into space (sometimes into proximity with a spatial body), in order to obtain new knowledge on conditions detected by the instruments of the vehicles.

SPACE SATELLITE A man-made satellite body that orbits the Earth, Moon, or other spatial body.

SPACE STATION A facility put into orbit by means of which, or from which, space travel or space exploration may be further effected.

SPACECRAFT A vehicle designed to fly primarily in space.

SPECIFIC IMPULSE The principal performance criterion for rocket engines. The specific impulse is the thrust delivered per unit flow of propellant (pounds of thrust per pounds/second of propellant). It is usually expressed in "seconds."

SPECTROSCOPE An instrument used to detect and analyze electromagnetic radiation in terms of its wave length.

SPEED OF SOUND The velocity at which sound travels. The speed of sound varies with the static temperature of the surrounding medium. In air on a standard day the speed of sound is 1108 feet per second or 756 miles per hour. A standard day is 59°F at sea level.

SPIN ROCKET A small rocket that imparts spin to a missile's airframe.

SPUTNIK The Russian name for unmanned satellites.

STABILIZED PLATFORM The major part of an all-inertial guidance system, composed of an assembly of gimbal frames that hold three accelerometers in a fixed position in relation to inertial space.

STAR TRACKER A telescopic instrument on a missile or other flight-borne object that locks onto a celestial body and gives guidance to the missile or other object during flight. A star tracker may be optical or radiometric.

STATIC TESTING The testing of a device in a stationary or hold-down position as a means of testing and measuring its dynamic reactions.

STELLAR Relating to a star or sun.

STRATEGIC MISSILE A long-range

missile employed in an Air Force strategic mission.

STRATOSPHERE A calm region of the upper atmosphere characterized by little or no temperature change with altitude. The stratosphere is separated from the lower atmosphere, or troposphere, by the tropopause. The stratosphere is free from the clouds and convective currents of the troposphere.

SUNSEEKER A two-axis device actuated by servos and controlled by photocells to keep instruments pointed towards the Sun despite rolling and tumbling of an aerospace vehicle in which instruments are carried.

SUPERCONDUCTIVITY A phenomenon, occurring in certain metals and alloys at extremely low temperatures, in which resistance to electricity disappears, and electric currents can be maintained indefinitely with no applied voltage.

SUPERSONIC Of or pertaining to the speed of an object moving at a speed greater than that of sound. (Technically, supersonic is generic and includes the concept of hypersonic, but some writers use it restrictively for relative speeds between Mach 1 and Mach 5.)

SURVEYOR A series of unmanned spacecraft designed for soft landings on the Moon, for the purpose of sending back data on lunar environment.

SYNCHRONOUS SATELLITE A satellite which revolves about the Earth once in 24 hours in an orbit over the equator. It thus remains fixed over a given point on the Earth.

TACTICAL MISSILE A guided missile employed in an Air Force or Army tactical mission.

TELEMETER An electronic method of sensing and measuring a quantity, as that of speed, temperature, pressure, or radiation, than transmitting radio signals to a distant station, where, indicated or recorded, they are interpreted by code.

TEST STAND A stand at which some mechanism or engine is tested out; specifically, a stand at which the static firing of a rocket engine is carried out to test thrust and other reactions.

THERMONUCLEAR Pertaining to nuclear reaction induced by heat, specifically to nuclear fusion.

THOR (SM-75) An Air Force intermediate range strategic bombardment missile that has a range of 1,500 nautical miles. The THOR first launched on January 25, 1957, was America's first intermediate range ballistic missile. It has been used for the main propulsion system for several nonmilitary missile experiments, including the United States' historic lunar probe of October 11-13, 1958.

THRUST The resultant force in the direction of motion due to the components of the pressure forces in excess of ambient atmospheric pressure, acting on all inner surfaces of the vehicle propulsion system parallel to the direction of motion.

THRUST CHAMBER A rocket motor or engine.

TIROS A series of meteorological satellites carrying two television cameras and two infra-red detectors.

TITAN (SM-68) An Air Force intercontinental ballistic missile that has

a range of over 5,500 nautical miles. Strategic bombardment missile powered by a liquid-rocket system. Prime contractor for the two-stage TITAN SM-68 is the Martin Company. TITAN I and its follow-ons, TITAN II and III, are excellent potential spacecraft boosters.

TRANSISTOR An electronic device that controls an electron current by the conducting properties of germanium or like material. (The transistor is similar to the vacuum tube in use but is itself a non-vacuum device.)

TRANSLUNAR SPACE That part of space conceived as a spherical layer centered on the Earth, with its lower limit at the distance of the orbit of the Moon, but extending to several hundred thousands of miles beyond. (This term is one of distance from the Earth, not one of the Moon's influence.) See AEROSPACE.

TURBOJET A jet engine whose air is supplied by a turbine-driven compressor, the turbine being activated by exhaust gases from the engine.

ULTRAVIOLET A form of electromagnetic radiation with wavelength just shorter than visible light.

UMBILICAL TOWER The tower which holds the "umbilical cable" carrying power and signals to and from a booster until it is launched.

UPPER STAGE A second or later stage in a multistage rocket.

V-2 A German-developed ballistic missile used in World War II.

VAN ALLEN RADIATION BELTS Two doughnut-shaped belts of high-energy charged particles, trapped in the Earth's magnetic field, which surround the Earth. Their minimum altitude ranges from approximately 100 miles near the Earth's magnetic poles to more than 1,000 miles at the equator. The maximum altitude of the outer belt extends to approximately 40,000 miles at the equator. These belts, which form an obstacle to interplanetary explorations, were first reported by Dr. James A. Van Allen of Iowa State University. See AEROSPACE.

VANGUARD The first U.S. satellite program, used for space science experiments.

VECTOR CONTROL The control of the direction of a rocket engine's thrust, as distinguished from thrust magnitude control.

VERNIER Named after Pierre Vernier, 1580-1637, the French mathematician. Small rocket engines or gas nozzles mounted on the outside of a missile or other vehicle which can be tilted by commands from the flight control system to control the roll, pitch, and yaw attitudes during propelled flight. Verniers are used to make the final adjustment of vehicle velocity as it approaches the thrust cut-off point. Also used in form of small peroxide rocket motors to provide control to aerospace vehicles such as the Air Force X-15, when aerodynamic controls become ineffective.

VOYAGER Designation of a series of spacecraft scheduled for unmanned flights to and soft landings on the planets Mars and Venus.

WAC CORPORAL An early liquid-propellant sounding rocket.

WEIGHTLESSNESS The absence of any apparent gravitational pull on an object. Any object deprived of support and freely falling in a vacuum is weightless. An orbiting satellite above the Earth's atmosphere is a special case of "free fall" as is an aircraft when flying a parabolic curve. The weightless condition is experienced in each case.

WIND TUNNEL A tunnel through which a stream of air is drawn at controlled speeds for aerodynamic tests and experimentation.

WINDOW A term denoting the space or time period in which a phenomenon can be observed or an action taken.

X The symbol for "experimental." When used as a prefix with the designation of an aerospace vehicle, it indicates that the designated item is an experimental model of the specified vehicle, *e.g.*, XSM-65.

X-15 A U.S. Air Force-NASA program, with some U.S. Navy financial support, for rocket-powered craft to be launched in midair from a B-52 (Stratofortress) to altitudes of 100 miles or more at speeds in excess of 3,600 mph. After flight in a semi-ballistic path in the partially space-equivalent zone of the atmosphere, the vehicle is piloted to a landing. Small peroxide rocket motors provide control at altitudes where aerodynamic controls become ineffective.

X-RAY A form of electromagnetic radiation between ultraviolet and gamma rays.

Y The symbol for "prototype." When used as a prefix in the designation of an aerospace vehicle, it indicates that the vehicle is a prototype model which is produced in limited numbers for operational tests, e.g., YTM-61.

ZERO GRAVITY The complete absence of gravitational effect, existing when the gravitational attraction of a primary is exactly nullified or counter-balanced by inertial force.

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